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ELECTRIC-RAILWAY SYSTEMS
LINE AND TRACK
LINE CALCULATIONS
MOTORS AND CONTROLLERS
ELECTRIC-CAR EQUIPMENT
MULTIPLE-UNIT SYSTEMS
SINGLE-PHASE RAILWAY SYSTEM

SCRANTON
INTERNATIONAL TEXTBOOK COMPANY
186

PRINTED IN THE UNITED STATES

BURR PRINTING HOUSE
FRANKFORT AND JACOB STREETS
NEW YORK

287

4843

186

CONTENTS

ELECTRIC-RAILWAY SYSTEMS

METHODS OF SUPPLYING CURRENT

1. Electricity is now generally conceded to be the most economical power for the operation of street railways. It has shown itself superior to horses, compressed air, or cable, both as regards flexibility and cheapness of operation. Cable roads may be advantageous in some very hilly localities; but for ordinary traffic, most of the cable roads installed some years ago have been converted into electric lines. Compressed air has been used in a few cases, notably in mining work, but for general purposes electricity has the field practically to itself.

2. So far, electric cars have been operated by direct current almost exclusively; that is, the current supplied to the cars is direct though the current supplied from the station may be alternating. On roads where a considerable amount of power has to be transmitted a long distance, alternating current is used in order that the transmission may be carried out economically at high line pressure, but even under such circumstances the general practice has been to step-down the alternating current and transform it to direct current before supplying it to the cars. On roads where the distance of transmission is not very long, direct current may be supplied from the station and the use of alternating current is unnecessary; if boosters are used, as described later, the radius of direct-current supply can be extended considerably.

The direct-current series motor is admirably adapted for traction work, and alternating current has not been used to

any extent on the cars for the reason that heretofore no alternating-current motor that could compete on all points with the direct-current motor has been available. A number of roads are operating in Europe on which polyphase induction motors are used, but the induction motor has never been used to any extent in America because it presents a number of disadvantages. It is essentially a constant-speed motor and is not well adapted for work where a variable speed, large starting torque, and decreasing torque with increasing speed are desired. Again, three-phase motors necessitate at least two trolley wires. However, it has long been recognized that the use of alternating-current motors on cars would simplify and cheapen the construction of roads on which alternating current must be used for the transmission of power. Rotary converters are dispensed with and it becomes possible to use a much higher pressure between the trolley wire and the rail. Within the last few years, a great deal of experimenting has been done on the use of single-phase motors for traction work, and it is probable that this type of motor will be largely used for interurban roads. A single-phase motor requires only one trolley wire, and the motors so far developed have speed and torque characteristics very similar to those of the direct-current series motor. It is safe to say, therefore, that in many future installations alternating current will be supplied to the cars and rotary-converter substations dispensed with on those roads where the conditions are such that direct current cannot be used economically for the transmission from the station.

VOLTAGE

3. The **voltage** at which current is supplied to the cars has in the past been limited principally by the conditions for sparkless commutation on the motors and also by considerations of safety. It is difficult to build direct-current motors that will operate without sparking or flashing under the severe conditions incidental to electric traction, if the pressure is over 650 volts. Also, in places where the trolley wire is

exposed, as in public streets or along public highways, the pressure should not be much over 500 volts on account of the danger to life. Thus, the general practice has been to use from 500 to 550 volts for city traffic and 600 to 650 volts for interurban traffic. Under conditions of heavy load, the pressure may be very much lower than these figures because of the large line drop. On interurban lines operating on a private right of way, there is no reason why a pressure higher than 650 volts could not be used between the trolley wire and track, provided that motors could be made to operate satisfactorily on the higher pressure. Experiments have shown that there is no special difficulty in collecting current at high pressure from an overhead trolley, though, of course, the wire has to be insulated better than is usual for ordinary 500-volt work. On the Berlin-Zossen experimental three-phase road, a trolley pressure of 10,000 volts was used without difficulty. With alternating-current motors, the current can be supplied at high pressure and stepped-down by means of a transformer carried on the car. The use of alternating-current motors will therefore in all probability be accompanied by trolley-wire pressures much higher than those customary with direct current, and a corresponding saving in the amount of copper required to supply current to the cars will be effected. The use of high trolley pressures will, of course, be confined to roads operating in places where the trolley wire will not be a source of danger.

METHODS OF CURRENT COLLECTION

4. Several methods are available for supplying current to the cars, but the one to be used in any given case is generally fixed by local conditions. The usual methods are given below in the order of the extent of their application.

1. By means of an overhead conductor or pair of conductors connected to the car by an under-running contact; this is known as the *overhead-trolley system*.

2. By means of contact or conductor rails run alongside of, or between, the car rails, contact being made with the

car by means of sliding shoes; this is usually called the *third-rail system.*

3. By means of underground conductors run in a conduit and connected with the car by means of a contact plow passing up through a slot; this is called the *open-conduit system*, or *slot system.*

4. By means of electromagnetic switching devices that make connection between the car and a conductor situated underground; this is usually called the *electromagnetic*, or *surface-contact*, *system.*

5. By means of storage batteries carried on the car; in this case no conductors between the power station and cars are necessary.

It will aid in understanding the various methods of railway power distribution to consider, very briefly, the main features involved in each method. The details will be taken up later in connection with line and track construction.

OVERHEAD-TROLLEY SYSTEM

5. The **overhead-trolley system** is more widely used than any of the others. For lines in towns or cities, when a road is run along a public right of way and where the live working conductor must be placed so that there will be no danger of accidental contact with it, the overhead-trolley system is the cheapest both as regards first cost and cost of maintenance.

Fig. 1 shows a simple trolley system supplied from a direct-current generator. The positive terminal of the generator connects, through the switchboard, to the overhead-trolley wire; the negative terminal connects to the rail, and the path of the current is indicated by the arrows. The current is carried to the moving car by means of the under-running trolley wheel. This arrangement, simple as it may seem, was not arrived at without considerable experimenting. In the early electric roads two trolley wires were used, and the track was not employed as one side of the circuit. This scheme is still used in a few

places, notably in Cincinnati. Also, on the first roads installed, the trolley wheel ran on top of the wire; but this method of collecting the current was soon superseded by the under-running trolley.

It should also be noted that the cars are operated in parallel. This is true of all systems of distribution where current is supplied to the cars from an outside source. All street-railway systems are, therefore, operated at approximately constant potential; i.e., constant or nearly constant pressure is maintained between the trolley wire and the track. Wherever connection is made from the trolley to the track through the motors, a current flows and the car is propelled.

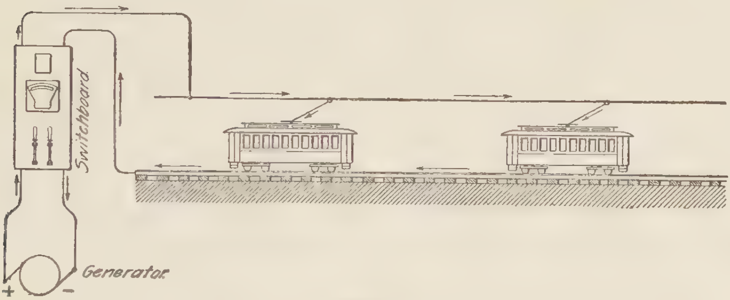


FIG. 1

Each car is independent of the others and takes an amount of current proportional to the power required to drive it.

The arrangement shown in Fig. 1 admits of many modifications. For example, except on very small roads, the trolley wire is not sufficiently large to carry the current necessary; so **feeders**, or heavy cables, are run to the station instead of carrying back the trolley wire itself. Also, in some cases, return cables are used in connection with the track. The overhead-trolley method is, at present, the only one that is available for the supply of current at high trolley pressures, the insulation provided by the other methods not being sufficient, to say nothing of danger from shock.

THIRD-RAIL SYSTEM

6. The **third-rail system** is, in principle, the same as the overhead trolley. The trolley wire is replaced by a third rail mounted on insulators to one side of the track, or between the tracks on double-track roads, and slightly above the other rails. Current is supplied to the car by means of shoes that slide on the contact rail and the current returns through the track rails, as in the overhead system. In a few special cases, two conductor rails have been used, the track not being employed to carry the return current.

Fig. 2 shows the arrangement of collecting shoe for an ordinary third-rail equipment. The third rail *a a* is of the standard T pattern and is supported on insulators *b* resting on every fifth tie, which is extended for this purpose. The cast-iron shoe *c* is suspended from links, so that it is free to move up and down through a limited range, and the whole collecting device is attached to a wooden beam *d* carried by the truck. Cable *e* leads to the controlling devices on the car and connection is made to the shoe by means of bare flexible copper cable or braid *f*, the links not being depended on to carry the current. In some cases, a copper fuse is placed at *g* to cut off the current in case of short circuits.

The third rail is much used for roads where the traffic is heavy and when the presence of the contact rail does not interfere with other traffic. It is the outcome of a demand for a construction more substantial than the overhead trolley and better adapted to high-speed work and the collection of large currents. The contact rail provides a working conductor of large cross-section and long stretches of track can be supplied with current without any feeder other than the third rail.

7. A No. 000 trolley wire has a cross-section of .132 square inch; a 70-pound rail has a cross-section of about 7 square inches. Taking the conductivity of the conductor rail as one-tenth that of copper, the rail will be equivalent to .7 square inch of copper, or 5.3 times the cross-section of the trolley wire. If especially soft steel were used for the

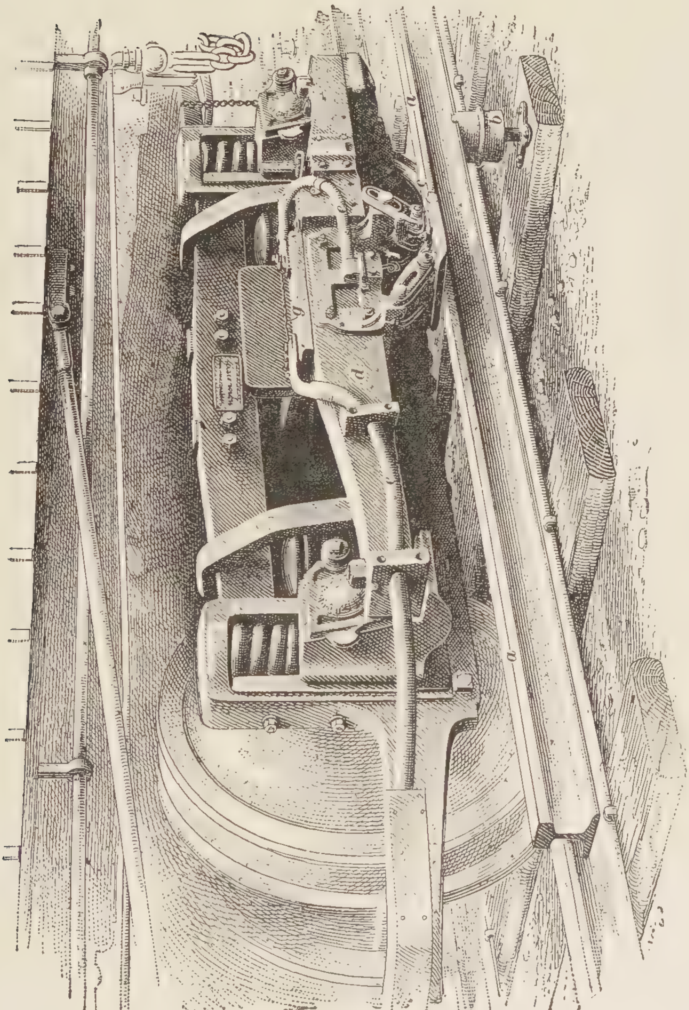


FIG. 2

third rail, the resistance might not exceed 7 to 8 times that of copper; but even with steel not especially made for high conductivity, a 60- or 70-pound rail will provide a much larger carrying capacity than a trolley wire of the size ordinarily installed. The third-rail construction is generally considered more expensive than the overhead trolley, but as a matter of fact it is cheaper when the comparison is made on a basis of equal current-carrying capacity.

8. This system is not without its disadvantages, and by some engineers it is thought that it will eventually give way to some kind of overhead construction more substantial than the ordinary trolley wire, or to some well-developed surface-contact system. There is unquestionably an element of danger in the exposed third rail even when the road is elevated, underground, or run on a private right of way carefully fenced in. The exposed live rail is in the way when track repairs are being made, though the trackmen soon become accustomed to it and accidents are surprisingly few. It is also very difficult to use it in yards and terminals, the numerous crossings of the tracks making the work very complicated and dangerous. On this account, on some third-rail roads the cars are equipped with overhead trolleys and all switching in the yards and at terminals is carried out by the overhead system.

OPEN-CONDUIT SYSTEM

9. The **open-conduit system,** because of the great expense of installation, is used only in a few large cities where the traffic is heavy enough to warrant the expense and where the city authorities do not permit the stringing of overhead-trolley wires and feeders. Current is supplied from two conductor rails placed in a conduit between the track rails. This conduit is closed at the top with the exception of a slot about $\frac{5}{8}$ inch wide, through which a plow suspended from the car passes. Two cast-iron shoes, carried by the plow, press sidewise against the conductor rails, and cables lead from the shoes to the motors on the

car. Fig. 3 illustrates the main features and Fig. 4 shows the arrangement of the plow in relation to the conductor rails. The conduit is made sufficiently deep so that mud and water will not interfere with the conductor rails, and at regular intervals sewer connections are provided. The two contact shoes *s, s* are pressed sidewise against the conductor rails *a, a* by flat springs *b, b*. Shoes *s, s* connect to cables *c, c*, which lead to the motors and controlling devices on the

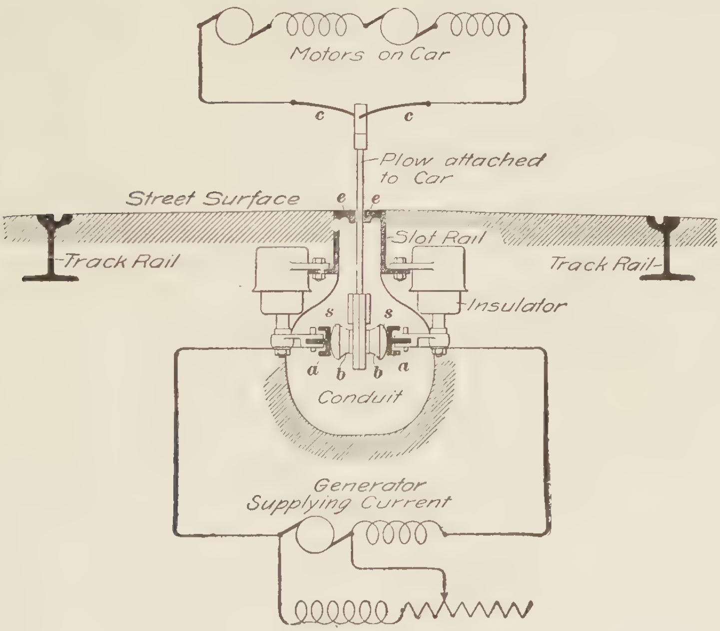


FIG. 3

car. The conductor rails *a, a* are connected to the power station by outgoing and return feeders run in ducts alongside the track. The part of the plow that passes between the slot rails *e, e* is made of steel plates riveted together, while tempered-steel wearing plates are fastened on the plow at the points where rubbing against the slot rails occurs.

While this system works satisfactorily if the conduit is kept properly cleaned, and avoids the use of overhead

conductors, it is not a generally applicable method. The cost of construction is from four to five times that of an overhead-trolley line, and it is only on roads having a dense traffic that it can be made to pay. The construction of the conduit in cities usually necessitates the removal or rearrangement of underground pipes, sewers, electric conduits, etc. that may lie in the path of the conduit, all of which increases the cost greatly.

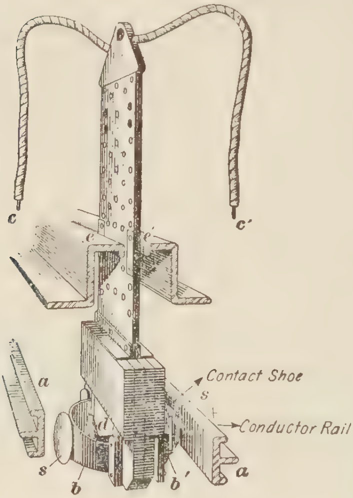


Fig. 4

ELECTROMAGNETIC, OR SURFACE-CONTACT, SYSTEMS

10. Surface-contact systems have not been used to any great extent though many such methods have been invented. In only a few special cases have they been used in the United States; but in England and also on the Continent of Europe a number of surface-contact roads have been in operation long enough to demonstrate their reliability and safety. These roads are more expensive to install than those using an overhead trolley, but they are less expensive than open-conduit roads, are cheaper to maintain, and are equally effective so far as avoiding overhead wires is concerned. It is reasonable, therefore, to expect that surface-contact systems will find wider application in the future than they have in the past. All electromagnetic systems are more or less complicated, and of all the switching devices that have been invented comparatively few have been commercially operated.

11. The general arrangement of such systems is shown in Fig. 5, where G is the generator with its negative terminal connected to the track rails, as in the overhead-trolley or third-rail systems. Insulated contact plates r, r are

mounted between the rails and project slightly above the pavement. In most systems, these contacts are in the form of small plates of hard steel designed to withstand the wear caused by traffic and by the current-collecting shoe on the car. Each contact is connected to the positive working conductor *m* through a switch *s* that is so arranged that the contact plate is connected to the live conductor only while the

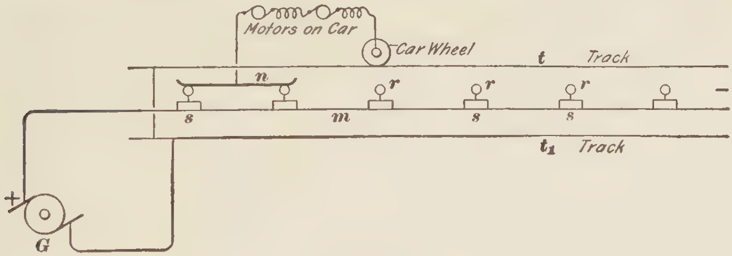


FIG. 5

car is over the plate. Thus, as the car moves along the switches operate, and the car is supplied with current by means of a shoe *n* that slides over the contact plates. In some systems, the switches are grouped in manholes, and operated electrically by means of solenoids or electromagnets; in others, the switches are placed under the contact plates and operated by means of powerful magnets carried underneath the car.

12. General Electric System.—Fig. 6 shows the essential features of the **General Electric surface-contact system,** which belongs to the class in which the switches are operated by means of solenoids. Two rows of contact studs *N*, *N* are placed between the rails; the negative terminal of the generator connects to the track rails and the positive conductor connects to one of the fixed contacts of each of the switches *K*, as shown. The operating coils of the switches are connected between the lower rail and the lower row of contact studs; the studs in the upper row are connected to the remaining fixed contacts on the switches as shown. Each car is equipped with a small storage battery *B*, which is kept charged by passing a portion of the motor current through it; this battery is used to operate the

surface-contact switches when the car is started and also for lighting the car. The car is equipped with two long shoes, and when it is in motion the current takes the path indicated by the arrows, flowing from the positive working conductor through the switch contacts to the upper contact stud, thence through the motor, or combination of motors, through the lower shoe and contact stud, and back to the rail by way of the magnet coil. The current passing through the coil holds up the switch, and as the car moves along, successive switches are

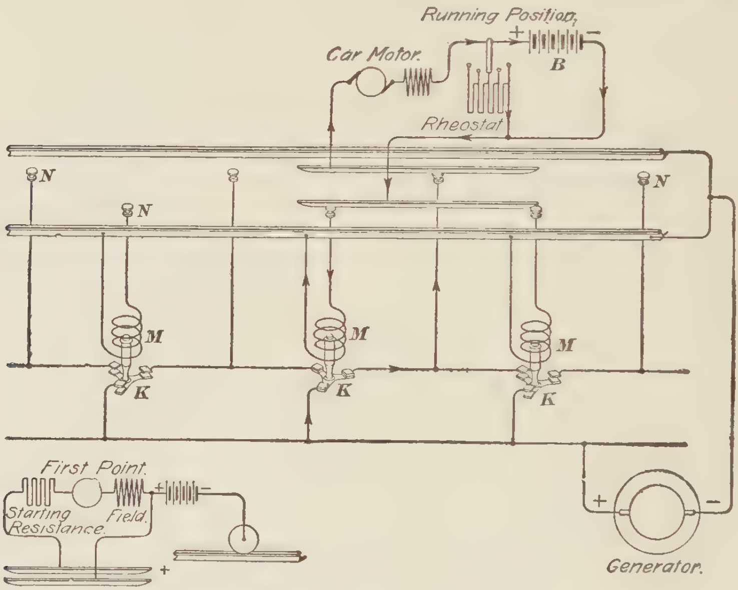


Fig. 6

brought into action, thus maintaining the path for the current through the car. The only live studs are those under the car, and as soon as the car moves off the studs become dead; there is thus no danger of shock unless some of the switches fail to operate. When the car is started, current must be supplied from the storage battery in order to operate the switch; this is done by making the connections at starting as shown in the small diagram, where the battery is connected between the lower shoe and rail, thus raising the switch and

allowing current to pass through the motors. As soon as the car has started, the main current operates the switches and the battery is no longer required for this purpose. By making the shoes long enough so that the forward stud is touched before connection with the one in the rear is broken, the forward switch will pick up before the rear one drops, thus maintaining the circuit and avoiding arcing at the switch contacts. In an actual installation, the switches are not distributed along the track, but those corresponding to about 200 yards of track are placed in a vault or manhole and connected to the studs by means of underground cables.

13. Lorain System.—As an example of a surface-contact system where the switches are operated by means of magnets carried under the car, the **Lorain system** may be taken. This method is in successful operation for regular city traffic, and continuous use has shown that the danger from shock on account of switches failing to work is negligible. A switch is placed directly beneath each contact plate. The upper switch contact connects to the plate and the lower contact to the working conductor through a flexible copper ribbon. The lower contact is mounted on a thin iron plate, and a series of magnets suspended under the car, with their poles near the surface of the ground, attract the plate with the lower contact and draw it up, thus bringing the lower contact against the upper one and establishing connection between the contact plate and the feeder. The contact plates and switches are placed 10 feet apart and the magnets under the car extend over a length of 16 feet. Thus, two switches are always closed at the same time; the forward switch is picked up before the rear one is dropped and there is no breaking of the circuit when a switch opens. The collecting shoe extends over two contacts, as in Fig. 5, and there is thus a continuous collection of current. As soon as the magnets pass from a switch, the iron plate, carrying the lower contact, drops, thus leaving the plate dead after the car has passed. The switch contacts are made of carbon so that there is very little danger of sticking.

A small storage battery is provided on the car to furnish current for energizing the magnets when the car is first started or to start the car after the current has been cut off from the line temporarily. Details as to the construction and method of mounting the switches will be given later in connection with track construction.

14. Sectional Third Rail.—Electromagnetic switching devices can be used for the operation of third-rail systems, where the contact rail is divided into a number of short sections that are energized only when the car is passing. In this case, the contact plates, Fig. 5, are replaced by short sections of third rail and the system is much safer than the ordinary one where the whole rail is energized from one end of the line to the other. Sectional third-rail systems are used, to some extent, for the operation of trains in tunnels and in other places where it is desired to reduce the danger from shock to a minimum.

STORAGE-BATTERY SYSTEMS

15. Many attempts have been made to operate electric street cars by means of storage batteries carried on the cars but none of them have proved really successful. The constant vibration and jarring soon cause the cells to deteriorate while the acid fumes given off by them have also proved a great drawback. It is not worth while devoting space to a consideration of cases where the storage battery has been tried and abandoned. For some special kinds of traction work, batteries have proved desirable; as, for example, the operation of small electric locomotives for use around manufacturing plants.

However, batteries may often be used to great advantage on railway systems when they are placed in power houses or substations to take up fluctuations in the load or to carry the whole load for short intervals. In work of this character, the battery is stationary and the deterioration is not nearly so great as when the cells are subjected to shocks and jars on a car. Moreover, a stationary battery can be made heavy enough to secure durability, whereas a street-car battery must be made as light as possible.

OPERATION BY DIRECT CURRENT

16. The simplest method of supplying current to cars is by direct current transmitted from the generators to the cars without the use of any intervening transforming devices. The ordinary 500-volt system with its connections has been explained, so that it is only necessary here to describe some special features connected with direct-current distribution that pertain particularly to electric railways.

The distance beyond which it becomes uneconomical or undesirable to operate cars by means of current transmitted at 500 volts depends so much on the character of the traffic and the frequency of the car service that it is difficult to assign any limits beyond which 500-volt distribution should not be used. Many roads are in successful operation where cars are operated 8 miles or more from the power station and, by installing storage batteries on the distant parts of the line, cars can be operated at greater distances without undue drop. On the other hand, roads with very dense traffic, as in large cities, cannot be operated for a radius of 8 miles from the power house without an excessive expenditure for copper. By careful laying out, however, there is no reason why most medium-sized roads cannot be operated over a radius of 6 to 8 miles by the 500-volt system and the use of alternating-current transmission is seldom necessary for such roads.

HIGH- AND LOW-POTENTIAL BUS-BARS

17. In many cases, the greater part of the traffic on a road is confined to a comparatively small area; lines run out to distant points, but the traffic on the outlying lines is light. By applying a higher pressure to the feeders running to these distant points, the pressure at the cars can be maintained without the installation of an alternating-current transmission plant. Thus, if two pressures, say 500 volts and 600 volts, are available at the station, the short feeders supplying near-by sections can be attached to the 500-volt bus and the long feeders running to outlying sections to the

600-volt bus, thus allowing a drop of 100 volts in the long feeders. By using this method, the district supplied may extend for a radius of 10 or 12 miles from the power house.

18. Fig. 7 illustrates a plan of connections where high- and low-potential bus-bars are provided. Generators *1*, *2*, *3* are compound wound, as is always the case in street-railway

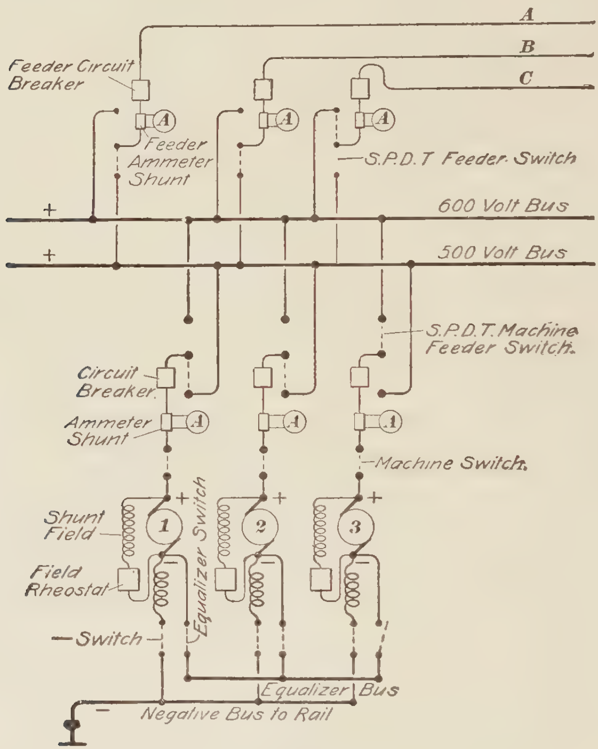


FIG. 7

power stations, and their − terminals are connected to the rail bus-bar. Each + terminal is connected through a main switch, ammeter, and circuit-breaker to the middle point of a single-pole double-throw switch, by means of which the + side of the generator can be connected to either the upper or lower bus-bar.

In Fig. 7, machines *1* and *2* are connected to the lower bar and are operating in parallel, their equalizing switches being closed. Machine *3* is connected to the upper bus, as indicated by the dotted position of the machine feeder switch. Most standard railway generators will generate 600 volts without difficulty, and machine *3* is supposed to generate 600 volts while *1* and *2* generate 500 volts. With the connections shown, any machine can be connected to either bus-bar. The feeders are also provided with single-pole double-throw switches to enable any feeder to be connected to either bus. Thus, if feeders *A* and *B* were supplying near-by sections, or if the load on them were light, they could be run from the 500-volt bus; while if feeder *C* supplied a distant or heavily loaded section it could be connected to the 600-volt bus by throwing its switch to the upper position, as indicated. By this method, a fairly uniform voltage can be maintained at the cars under widely varying conditions of load and distance of transmission. It should be noted, Fig. 7, that the generators are equalized on the — side, a practice that is now very common in railway plants. The — main switch and the equalizer switch are mounted side by side near the machine, and the negative leads are carried directly to the rail bus, thus simplifying the conditions.

BOOSTERS

19. When a road operates several sections a long distance from the power house, the generators, even when run at 600 volts, may not furnish sufficient pressure to make up for the large drop in the feeders. In such cases the road may be operated, without using high-pressure alternating-current transmission, by using *boosters* in connection with the main generators. A **booster** is a generator connected in series with the feeder or feeders on which the voltage is to be raised, in such manner that the voltage that it generates is added to that of the main generators, thus increasing the voltage applied to the feeders by the amount of the pressure generated by the booster.

In Fig. 8, *a* represents the armature of the main generator and *b* the booster armature. Short feeders supplying near-by sections are connected to the + bus-bar of the generator in the usual manner. Long feeders are connected to the + bus-bar through the booster, which in this case is supposed to generate 200 volts. For railway work, boosters are nearly always of the series type; i. e., the field winding is in series with the armature so that the voltage generated increases in proportion to the current that passes through the booster. Thus, when the load on the long-distance feeders

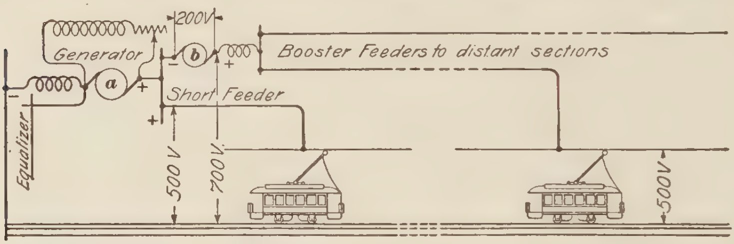


Fig. 8

is light, the booster voltage is low because the field is weak. When a heavy load comes on, the booster voltage increases and automatically compensates for the drop in the long feeders supplied through the booster. If the booster were shunt or compound wound and thus generated a practically constant voltage regardless of the current supplied over the feeders, an excessive voltage would be applied to the cars at light loads because there would then be little loss in the line to take up the booster voltage.

20. Method of Driving Boosters.—Boosters are nearly always driven by means of shunt-wound motors. Fig. 9 shows a typical General Electric booster set, consisting of a shunt-wound motor *M* coupled to a series-wound booster *B*. Boosters do not differ in their general construction from other dynamos, except that their commutators are often larger than on standard generators, because of the large current that they carry in proportion to their size. Boosters could be driven by steam engines or any other convenient

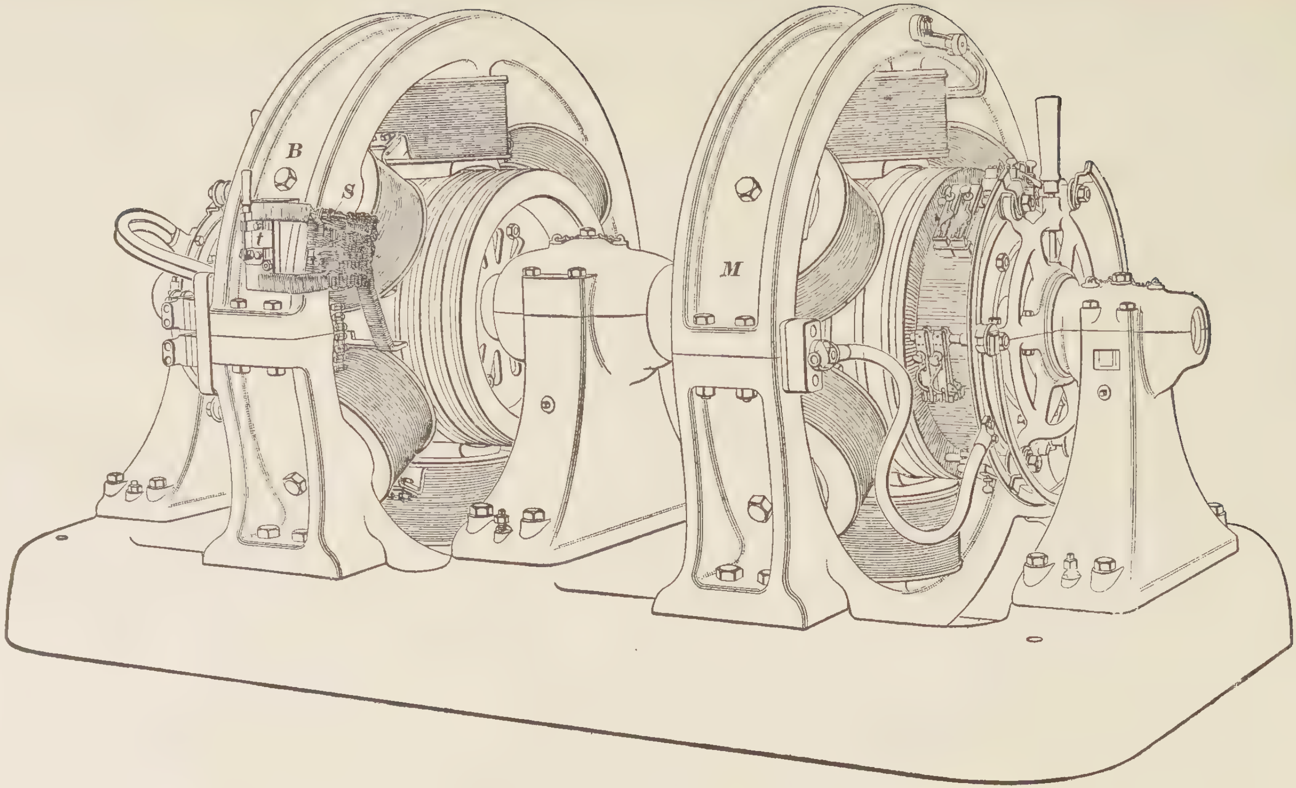


FIG. 9

source of power, but in most railway power plants electric motors supplied from the main generators are used.

21. Output of Boosters.—The output of a booster, in watts, is equal to the product of the number of amperes passed through the booster and the number of volts by which the pressure is raised. Thus, if a booster carries 600 amperes, and if when this current is passed through it 200 volts is generated, the output of the booster is $600 \times 200 = 120,000$ watts, or 120 kilowatts. If the current dropped to 300 amperes, the voltage generated would, since the booster is series-wound, drop to about half the full-load voltage, i. e., 100 volts, and the output would then be $300 \times 100 = 30,000$ watts, or 30 kilowatts. Thus, the loss in the line is compensated for automatically and the voltage at the cars remains nearly constant notwithstanding fluctuations in load.

The booster output for any given case will depend on the current taken by the feeders that require boosting. A common size that has been found well adapted for average railway service has an output of 120 kilowatts, or 600 amperes at 200 volts. For smaller roads, an output of 60 kilowatts or 600 amperes at 100 volts will be found convenient. The booster shown in Fig. 9 is provided with a shunt S connected across the field winding. When switch t is closed, part of the current flows through S and the voltage added by the booster is less than when t is open. Thus, the boosting effect can be changed in case the feeder does not require the addition of the full booster voltage.

22. Booster Connections.—A booster must always be connected in series with the feeder or group of feeders in such manner that its voltage will be added to that of the main generators. Thus, the — terminal of the booster must connect to the + bus-bar of the generator. Fig. 10 shows a plan of connections for a motor-driven booster. The main generators *1, 2, 3* connect to the + bus-bar in the usual manner and the + bus connects to the — booster bus through switch a. Each feeder is provided with a double-throw single-pole switch b, by means of which it can be connected

either to the main + bus or to the + bus of the booster. As indicated by the dotted lines, the long feeders *A*, *B* are connected to the booster, while short feeder *C* is supplied with current directly from the main generator. The booster is driven by a shunt motor supplied with current from the main generators, and equipped with a circuit-breaker and

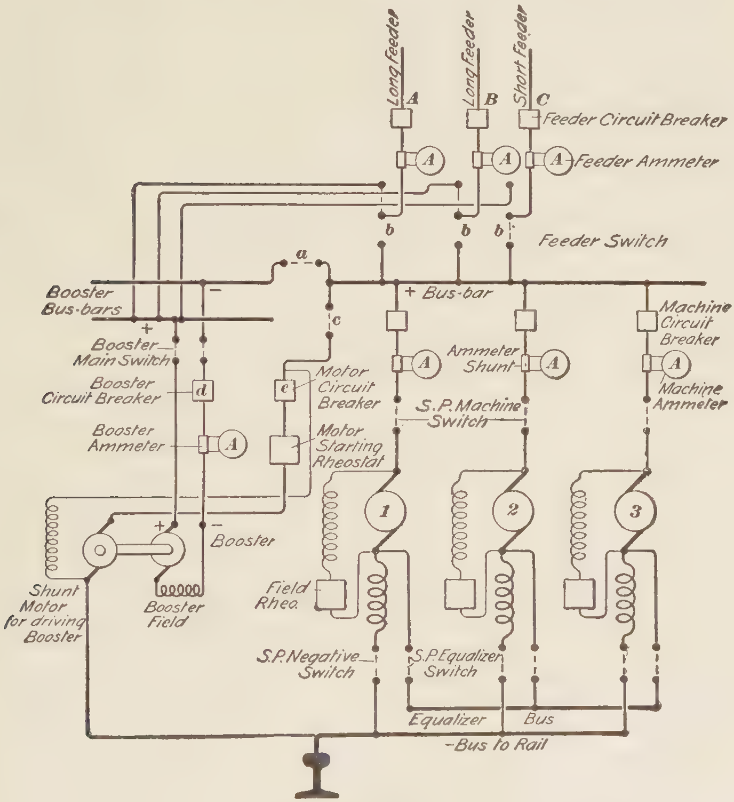


FIG. 10

starting rheostat. The booster is connected to the booster bus-bars through an ammeter, circuit-breaker, and double-pole main switch. By following out the connections in Fig. 10, they will be found equivalent to the elementary connections in Fig. 8; all current supplied to feeders *A* and *B*

passes through the booster and the voltage applied to them is increased by an amount proportional to the current.

The motor circuit-breaker should be arranged so that in case it opens the motor circuit, the current will also be cut off from the booster. The simplest way of doing this is to mount the two circuit-breakers *d*, *e* side by side and have them interlocked so that when *e* flies out, *d* will also open. They should also be arranged so that *d* cannot be closed until after the motor has been started.. If current were cut off from the motor but not from the booster, the latter would be driven as a series motor and an unloaded series motor on a constant-potential circuit will race badly. If, therefore, the current is not shut off promptly damage may result.

23. Booster Used With High- and Low-Potential Bus-Bars.—By combining a booster with the connections shown in Fig. 7, a number of voltages may be made available. Thus, in Fig. 11, the long feeders *A*, *B* are con-

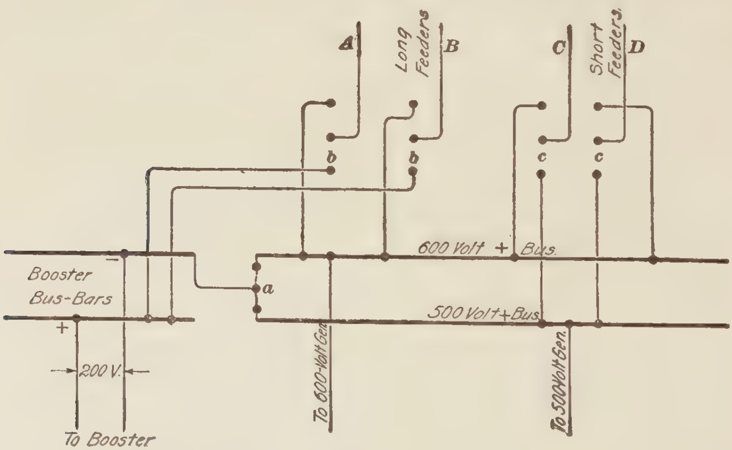


Fig. 11

nected to double-throw switches *b*, *b*, by means of which they can be connected either to the booster or to the 600-volt bus. The shorter feeders *C*, *D* can be connected through double-throw switches *c*, *c* to either the 500-volt bus or 600-volt bus. A double-throw switch *a* permits the

booster to be connected to either machine bus. Thus, assuming that the maximum booster voltage is 200, the maximum voltage applied to feeders *A*, *B* may be either 600 or 800. Short feeders can be supplied with either 500 or 600 volts, thus giving a flexible arrangement that allows the voltage to be suited to the demands of any particular section of the road.

24. Convertible Booster.—It is possible to arrange one of the regular station generators so that it can be used as a booster if necessary; this is often convenient on small roads or for temporary work where it would not pay to

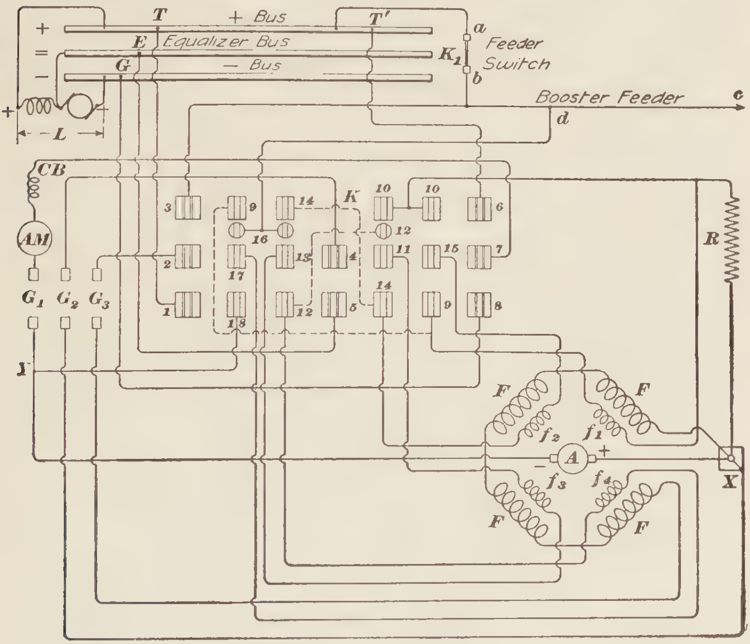


FIG. 12

install a regular booster. A machine so used should be arranged so that it can normally be run as a regular generator and by means of suitable switches changed over to act as a booster, as shown in Fig. 12, where *L* is one of the regular generators connected to the bus-bars.

In this case the +, −, and equalizer bars are shown together, but the negative and equalizer bars may be located near the generators; also, the machines are shown equalized on the + side; but this is immaterial so far as the general plan of connections is concerned. The convertible booster is shown in the lower right-hand corner, F, F, F, F being the series field coils and f_1, f_2, f_3, f_4 the shunt coils. With a machine of this kind, the series coils alone will not give sufficient excitation, so that it is necessary to use the shunt coils also. G_1, G_2, G_3 are the main generator switches and K is a special double-throw switch for changing over the connections so that the machine acts either as a booster in series with the booster feeder or as a regular generator in parallel with L or other generators that may be in service. When K is thrown to the upper position, the machine acts as a booster; but before it can do so, feeder switch K_1 must be opened. When K is thrown up, block *2* is connected to *3*; *7* to *6*; blocks *9*, *14*, *16*, *17*, and *13* are connected together, as are also blocks *10*, *11*, *12*, and *15*. The series coils of the machine are connected in series, but the shunt coils are connected to separate terminals so that they can be connected in series when the machine is used as a generator and in parallel when used as a booster. T' and b are the terminals of the booster and when K_1 is closed, the feeder connects directly to the bus-bar, the booster terminals being short-circuited. When K_1 is open, all current supplied to the feeder must pass through the booster. Neglecting the shunt field for the present and assuming that K_1 is open and K thrown to the upper position, the path of the current from generator L is as follows: $L+-T-T'-6-7-CB$ (circuit-breaker)$-AM$ (ammeter)$-G_1-A- -A+ -X-F-F-F-F-G_3$ $-2-3-c$ and back to $L-$ by way of the cars and track. When K_1 is closed, the path is $L+-T-a-K_1-b-c$, and the booster is cut out. The shunt field is excited by connecting the four coils in parallel so that a low voltage will provide sufficient excitation. The voltage for exciting the shunt coils is obtained by connecting them in parallel with a certain length of the feeder, thereby subjecting them to a

pressure equal to the drop in that part. Thus, the shunt coils are subjected to a voltage that varies with the current supplied over the feeder and their excitation will be proportional to the current; their effect will, therefore, be the same as if an equal number of ampere-turns were supplied by coils connected in series. One end of coil f_1 connects to block *9* and the other end to *10*; the ends of f_2 connect to blocks *14* and *15*; f_3 to *11* and *13*; and f_4 to *12* and *17*. When the booster switch is thrown up, similar ends of the shunt coils are connected together, positive ends being connected to blocks *10*, *11*, *12*, and *15* and negative ends to *9*, *13*, *14*, and *17*. Block *16* connects to the feeder at some point d determined by the amount of feeder required to give the drop necessary for the excitation of the shunt field. When switch K is thrown down, the path of the current is $A+-X-F-F-F-F-G_3-2-1-T$; out on the line by way of switch K_1 and feeder c to the cars and thence back to the rail bus-bar G through $8-7-CB-AM-G_1-A-$. The shunt coils are now in series, as shown by the path $A+-X-R-f_1-9-15-f_2-14-11-f_3-13-12-f_4-17-18-Y$ and current flows through them in the same direction as through the series coils.

25. Location of Booster.—Boosters are nearly always located in the power house. If located at any point out on the line they will, as a rule, entail an additional charge for attendance; and if motor-driven the power for their operation will have to be transmitted from the station, thus increasing the line loss. If the boosters were driven from some other source of power, this latter objection would not count, but there would still be the cost of attendance, which amounts to practically nothing when the boosters are placed in the power station, as they require such a small amount of attention that no additional help is required.

26. Economy of Booster.—At first glance, the use of boosters for supplying distant parts of a railway system appears to be a very uneconomical method and that it would be much better to use high-tension alternating-current transmission with substations situated near the outlying districts.

It takes power to drive a booster, but it is only expended while it is needed, and the load on a given booster may be quite light for the greater part of the time. That is, a booster wastes a considerable amount of power only when the load is heavy. Again, with alternating-current transmission there is considerable loss in the transforming devices that is the same no matter what the useful load on a substation may be, and the annual cost of attendance alone for a substation may more than counterbalance the cost of power wasted by a booster, as compared with the cost of power wasted with alternating-current transmission. The use of boosters allows a given system to be extended without making any change in the generating equipment already installed, and distant sections can be fed without an excessive outlay for copper. These advantages are still more fully realized if storage batteries are installed out on the line and charged from the booster feeders. The batteries will charge during periods of light load and discharge when the load is heavy, thus keeping a fairly uniform load on the feeder and working it to best advantage.

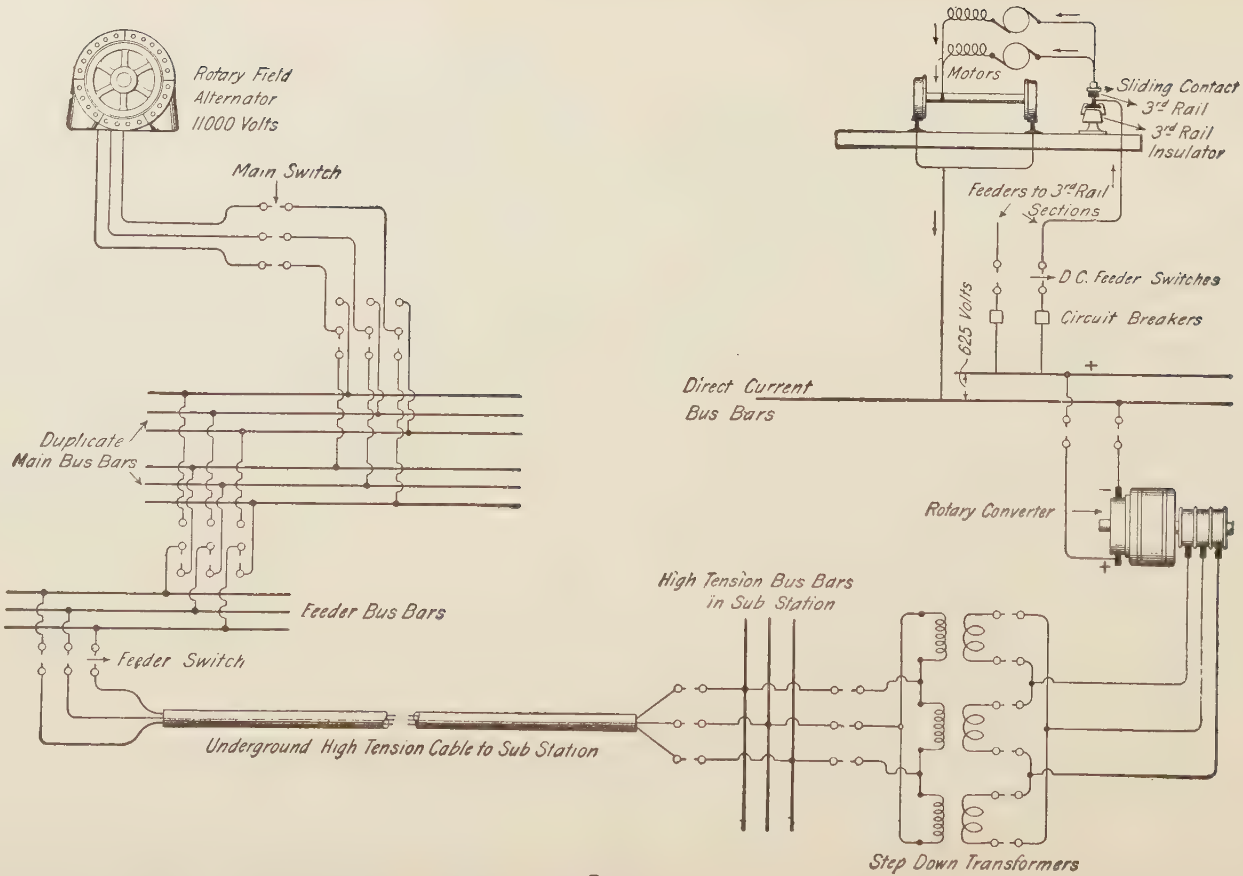
It is thus seen that the annual cost of operation with boosters may be actually less than with alternating-current transmission, and the question as to which is the best method for a given road is one that can only be decided by a very careful comparison of the cost of operation under the two systems. Roads are in regular operation where cars are run over a radius that in some cases exceeds 20 miles, by the use of boosters and storage batteries. These roads give satisfactory service, they are fully as economical in their operation as similar roads for which alternating-current transmission is used, and are less liable to interruptions from breakdowns in the various transforming appliances necessary with alternating-current transmission and direct-current distribution from substations.

ALTERNATING-CURRENT SUPPLY

POLYPHASE TRANSMISSION

27. Where roads are such that it is necessary to transmit the power for their operation by means of high-tension alternating current, the general practice has been to use two-phase or three-phase transmission and change to direct current by means of rotary converters located in substations. In some cases, as, for example, at Niagara Falls, current is generated by two-phase machines and transmitted as three-phase by connecting the step-up transformers on the Scott plan. On some of the largest systems, the alternators are wound for pressures as high as 11,000 volts and feed directly into the distributing system without the use of step-up transformers. Revolving field alternators are now almost universally installed in preference to those of the revolving armature type.

28. Fig. 13 shows the general scheme of distributing current for the Manhattan Elevated Railway, of New York. Current is generated in one large central station by revolving-field three-phase alternators direct-connected to 8,000-horsepower engines. The use of the revolving-field type of machine enables the current to be generated at 11,000 volts in the machine. It is distributed by means of heavily insulated lead-covered cables, run in underground conduits, to a number of substations, and there passed through stationary transformers that step-down the voltage. The rotary converters change the alternating current to direct current at about 625 volts, and from the substations it is supplied to the cars by means of a third rail and the ordinary track. The systems of distribution used by the Metropolitan Railway Company, of New York, and the London Underground are almost exactly the same as this one, except that the distributing pressures are somewhat lower. In the case of the Metropolitan road the distributing pressure is 6,600 volts.



Rotary Field
Alternator
11000 Volts
Main Switch
Duplicate
Main Bus Bars
Feeder Bus Bars
Feeder Switch
Underground High Tension Cable to Sub Station
High Tension Bus Bars
in Sub Station
Step Down Transformers
Rotary Converter
Direct Current
Bus Bars
625 Volts
Circuit Breakers
D.C. Feeder Switches
Feeders to 3rd Rail
Sections
Motors
Sliding Contact
3rd Rail
3rd Rail
Insulator

FIG. 13

On some roads, where a considerable part of the power is required near the station in the form of direct current, it may be advisable to use double-current generators and step-up the alternating current for transmission to the distant parts of the system. In most cases, however, where both alternating and direct currents are required it is better to install alternators, which are simpler than double-current machines, and obtain what direct current is required by means of rotary converters.

SINGLE-PHASE TRANSMISSION

29. The use of **single-phase motors** on electric cars is such a recent development that practice has not become settled regarding the best methods of distribution to be used. A number of plans are available and the one adopted in any given case will depend largely on whether the road is to be supplied from an existing transmission system or

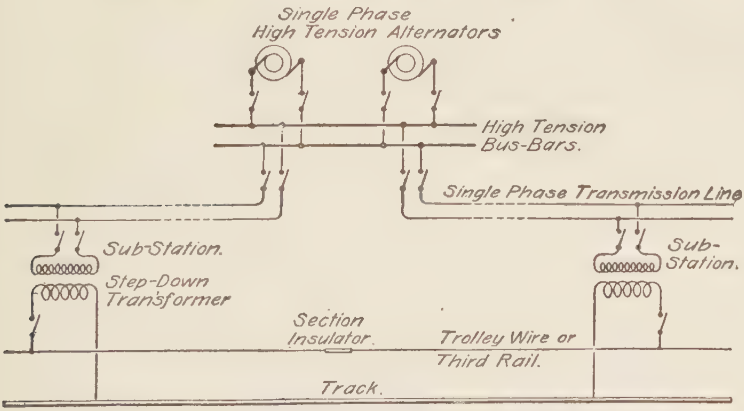


FIG. 14

whether new apparatus is to be installed throughout. Fig. 14 shows a plan where single-phase generators are used, the line voltage being stepped-down by transformers. This is the simplest plan and the one that would quite likely be adopted in case a new outfit were to be installed throughout. The trolley might be worked at a pressure of 2,000 to 3,000 volts

and the transmission carried out with a line pressure of 20,000 or 30,000 volts. It should be noted in Fig. 14 that adjacent sections of the trolley wire are at the same potential and that, under ordinary working conditions, there is no electric strain on the insulator used to divide the trolley wire into sections.

There are so many large transmission plants already in operation on the two-phase and three-phase systems that cases will frequently arise when single-phase railroads must be operated from them. This can be done by splitting the road into a number of sections and distributing them on the different phases so as to keep the load approximately balanced, thus

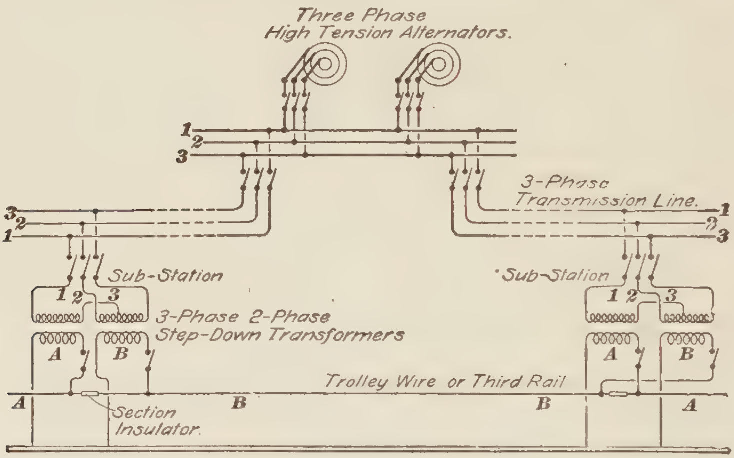
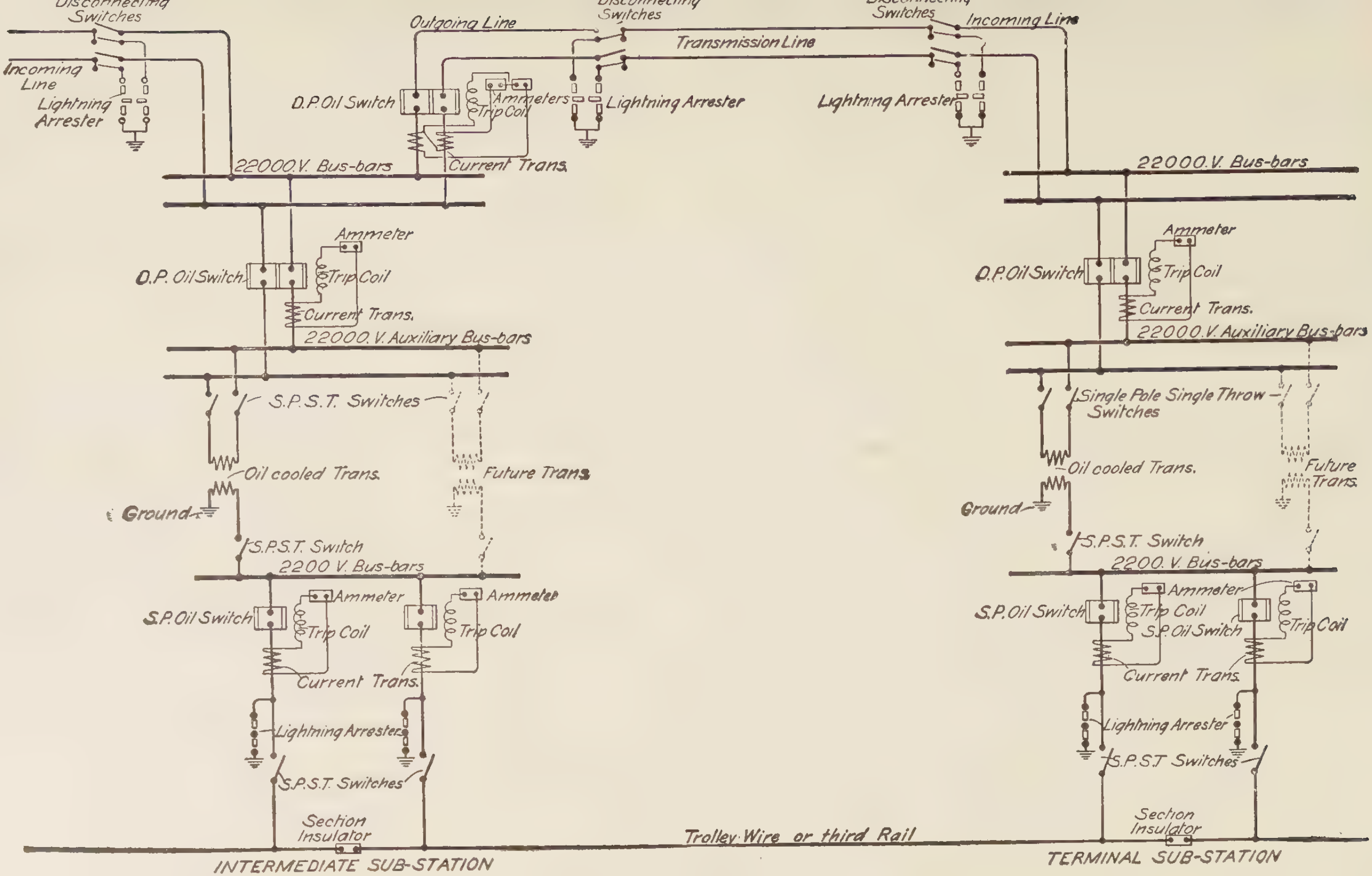


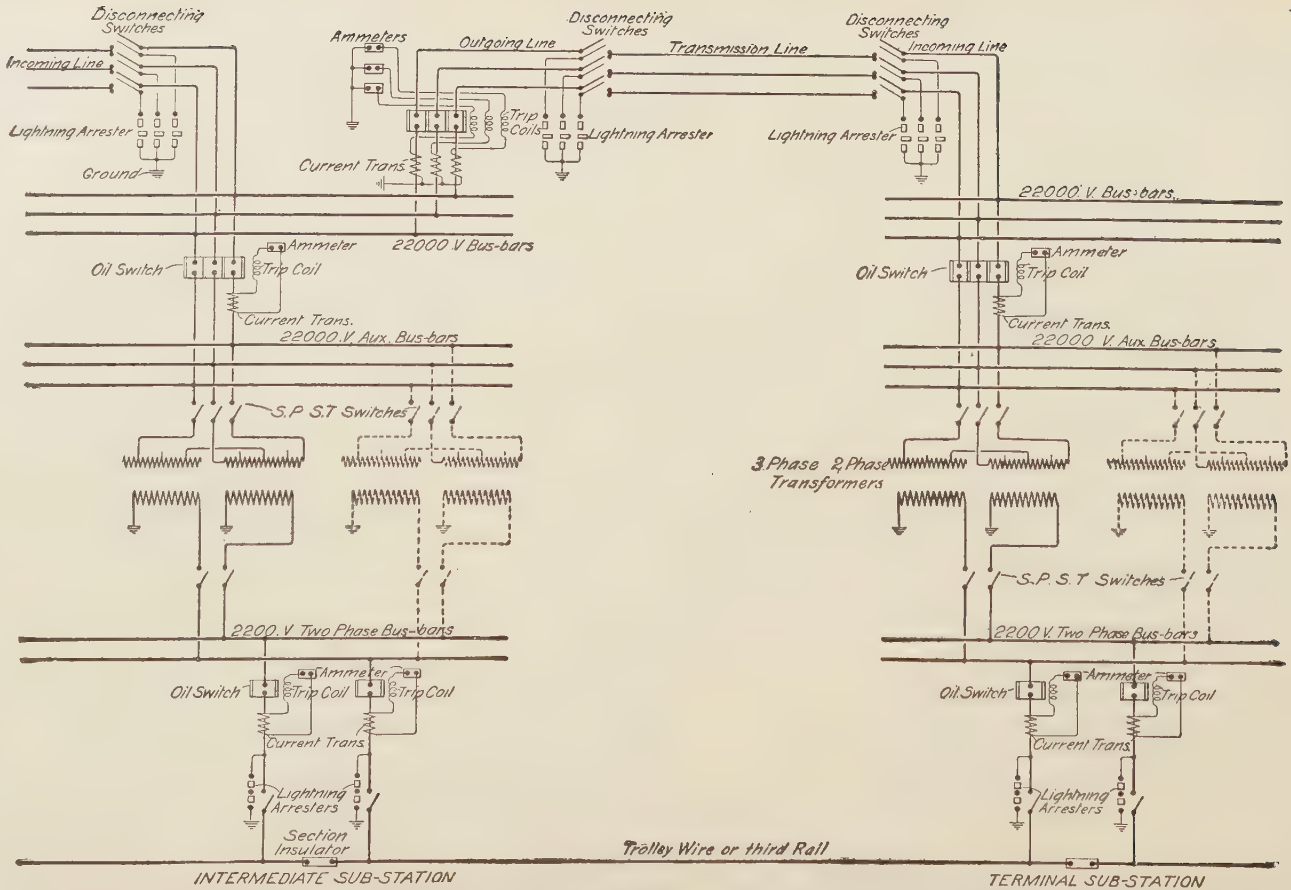
Fig. 15

making the system more complicated than if single-phase distribution were used throughout. Fig. 15 shows a scheme whereby a single-phase road is supplied from three-phase alternators. In the substations, the current is transformed from three-phase to two-phase by the Scott arrangement of transformers and alternate trolley sections are fed from different phases, thus balancing the load. By transforming from three-phase to two-phase, the secondary connections are considerably simplified. With this plan the trolley-section insulators are always subjected to a high pressure.



Switches
Incoming Line
Lightning Arrester
Outgoing Line
D.P. Oil Switch
Ammeters
Trip Coil
Current Trans.
Transmission Line
Lightning Arrester
22000.V. Bus-bars
Ammeter
Trip Coil
Current Trans.
22000.V. Auxiliary Bus-bars
S.P.S.T. Switches
Oil cooled Trans.
Future Trans.
Ground
S.P.S.T. Switch
2200 V. Bus-bars
S.P. Oil Switch
Lightning Arrester
S.P.S.T. Switches
Section Insulator
INTERMEDIATE SUB-STATION
Trolley Wire or third Rail
Single Pole Single Throw Switches
TERMINAL SUB-STATION

Fig. 16



Disconnecting Switches
Incoming Line
Lightning Arrester
Ground
Ammeters
Outgoing Line
Disconnecting Switches
Transmission Line
Disconnecting Switches
Incoming Line
Trip Coils
Lightning Arrester
Lightning Arrester
Current Trans.
22000 V Bus-bars
22000 V. Bus-bars
Oil Switch
Ammeter
Trip Coil
Current Trans.
22000 V. Aux. Bus-bars
Oil Switch
Ammeter
Trip Coil
Current Trans.
22000 V. Aux Bus-bars
S.P. S.T Switches
3 Phase 2 Phase Transformers
S.P. S.T Switches
2200 V Two Phase Bus-bars
2200 V. Two Phase Bus-bars
Oil Switch
Ammeter
Trip Coil
Trip Coil
Current Trans.
Lightning Arresters
Section Insulator
Oil Switch
Ammeter
Trip Coil
Current Trans.
Lightning Arresters
Trolley Wire or third Rail
INTERMEDIATE SUB-STATION
TERMINAL SUB-STATION

Fig. 17

30. Figs. 16 and 17 show substation connections for single-phase railways as proposed by the General Electric Company, Fig. 16 showing substations supplied from a single-phase transmission line and Fig. 17 from a three-phase line. The plans are the same as indicated in the elementary diagrams, Figs. 14 and 15, the three-phase current being transformed to two-phase in Fig. 17. Two substations feed into the same trolley section, thus dividing the load between the stations. The substation connections are very simple when compared with those for a station using rotary converters. All that is required in addition to the step-down transformers are the switches and protective devices. There is no moving machinery in the substations, constant attendance is unnecessary, and the use of single-phase motors makes the system as a whole nearly as simple as one using direct current. All switches used for interrupting the current are of the oil-break type; knife switches are provided for disconnecting various parts of the system, but these are not intended for opening the circuits when the current is on.

THE POWER HOUSE

31. Having explained the general methods of supplying current to electric cars from the working conductor, and the different systems available for transmitting the current from the central station to the cars, it will be necessary to take up the different parts of the road and describe them in detail. For this purpose the subject may be considered under the following heads: (*a*) The *power house*; (*b*) the *line and track*; (*c*) the *car equipment*.

LOCATION OF POWER HOUSE

32. The general design of power houses and the class of apparatus to be used in them has been fully covered elsewhere, so that only a few considerations affecting their location will be mentioned here. The power house, or power station, should be situated as near the center of the system

as possible, assuming that it is to be a steam-power plant and that its location is not already fixed by conditions having no connection with the traffic on the road. In the case of water-power plants the site is fixed by the location of the water-power, so that the following cannot, in general, be applied to such roads. By the center of the system is meant the center of the load or traffic. Since wires must be used to convey the power from the power house to the point where it is to be used, a part of the power generated will be lost in them. If they are not of sufficient size, they will cause a loss of power that will make itself very strongly felt in its effect on the speed that the cars make and also on the amount of heat that the motors develop. This loss will

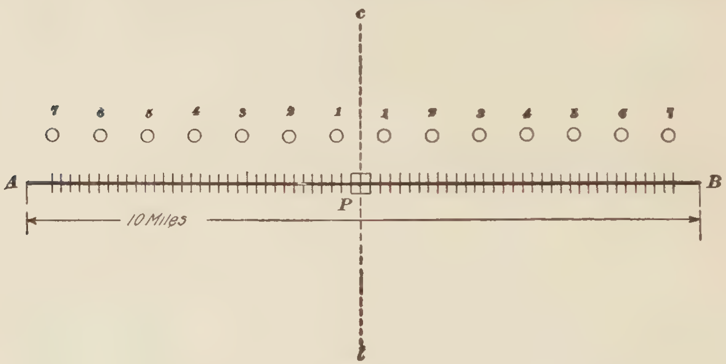


FIG. 18

depend on the resistance of the line and the amount of current that it has to carry. Hence, it follows that the center of the load may not be the geographical center of the system; in fact, these two centers very seldom fall in the same place. The true load center is located in the same way that the center of gravity of any system of bodies is located. The geographical center depends on the number of miles of track and how these are disposed; the load center depends on how the load is distributed.

In Fig. 18, AB represents 10 miles of track, free from grades and sharp curves, and on which a certain number of cars, *1*, *2*, *3*, *4*, etc., of about the same weight and equipped

with motors of the same size, run at regular intervals. The geographical center, or center of mileage, is in this case located at *P*, a point midway between the two ends, so that there is 5 miles of track on each side of it. Also, the load center in this case is at *P*; for, suppose that all the cars, except the two on the extreme ends, are running at full speed. Since the track is level and the cars and motors are alike, they will all take about the same power, and since the loads are evenly distributed throughout the length of track, they can be represented by circles of the same size, as shown in Fig. 18. Here there are seven loads on each side of the center line, and if each circle is supposed to represent a weight of a certain number of pounds, the center of gravity of the system will fall on the center line *c l*. So, also, if all cars, except the two end ones, are supposed to stand still or to coast along with the power off, and the two end ones start at the same time, the same load will be drawn to both ends of the line, and point *P* will still be the center of load and will therefore mark the spot where the power house should stand.

It is not implied that the load, even on such a simple layout, will always be as evenly distributed as in this ideal case, for such a condition will be the exception rather than the rule. Suppose *A* to be in the outskirts of a large city and *B* a down-town district; then, in the morning and evening, when people are going to and returning from work, the load leans a little toward the *B* end of the line, but during the rest of the day it is uniformly distributed. To alter conditions, suppose that from the middle of the line to *B* there is an up grade. Those cars that are ascending the grade will be called on to do more work than those on the level or on down grade, so that the ideal site for the station will be shifted toward *B*. In this case, the mileage center remains the same, but the load center is changed.

33. Influence of Future Extensions.—In locating the site for the power house, future extension and increase in traffic incidental to the development of outlying districts should be borne in mind and the site selected accordingly.

Suppose, in Fig. 19, that the full-line section AB represents the track put down at the first building of the road and that, in accordance with the demand then existing, the power house was put at P, the center of load for AB, which is supposed to be level. Now, suppose that the road has been extended to a point C, so that $AB = AC$. If it is further assumed that the district through which AC runs becomes built up, it will be only a matter of time when the travel density will be as great on the new stretch of track as on the old, in which case, assuming the different load units to be fairly evenly distributed throughout the distance BC, the proper place for the power house would be at point P', midway between B and C. So long as AB constituted the

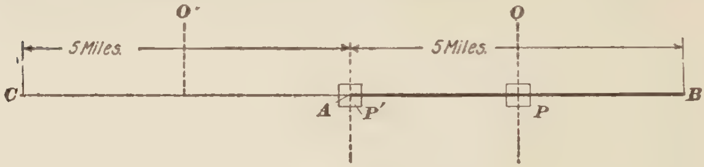


FIG. 19

whole road, the power house situated at P was at the center of an evenly distributed load, and the same loss of power would attend the transmission of a given amount of power to one end of the line as to the other. As soon, however, as the extension AC was started, a power house at P was $2\frac{1}{2}$ miles from the B end of the road and $CA + AP$ or $7\frac{1}{2}$ miles from the C end. Under such a condition, should all the cars, through trouble of some sort, become congested at the far end of the line, the loss incidental to the great distance and to the large current caused by trying to start all the cars at once would seriously delay getting the cars on their time again.

If the station were put at A in the first place, it would, of course, be at one end of the line as long as AB was the whole road, and would not therefore be at the center of load; but if the extension AC were only a matter of time, it would be far better to put up with the line loss due to want of balance on the shorter line, locate the station at A, and

be prepared to get the best results when the extension was in operation.

34. If, in deciding the best location for the power house, it were only a matter of fixing the probable center of load, the problem would be comparatively easy. But in many cases it is made very hard and almost impossible to solve, except approximately, by the fact that several other considerations enter into the question. The prospective center of the load might be located, from a purely electrical point of view, in a place so situated that every pound of coal to be burned under the boilers must be hauled to the power house. Or, it might fall in a place where it would be difficult to get water for the boilers and the condensers; such a place would, of course, be out of the question. Finally, the question of land comes in. It would be very poor engineering to build a power house in a part of a city where a city building would probably pay as good dividends as many well-managed roads. The final selection of a site for the power house must, in many cases, be a compromise between conflicting conditions. Load conditions will point to one site; good, cheap water will point to another; the coal bunkers should be arranged so that the coal may be passed directly to them from the boat, or from a coal car that can be run alongside of them by means of a siding or a spur from the main line.

DETERMINING THE LOAD CENTER

35. In the following method used for obtaining the load center, it is assumed that in all cases the layout of the road is along the lines shown in the diagrams, and that there are no limitations imposed by coal, water, and property requirements, the selection of a site for the power house resolving itself to the determination of the load center. To find the load center, the engineer must have a knowledge of the traversed district. With this in hand, the problem can be treated graphically, and amounts to the same thing as finding the center of gravity of a system of bodies. As an example, in Fig. 20, W and W' are two bodies whose centers are

11 feet apart, and each of which, for example, weighs 20 pounds. Since, in this case, the two weights are equal, the distance of their centers from the center of gravity P must also be equal, in order that $W l$ shall equal $W' l'$. The

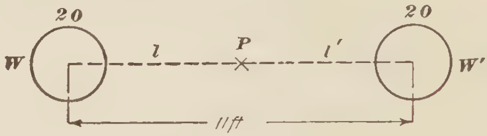


FIG. 20

center of gravity is, therefore, midway between the two bodies, and the system, as a unit, acts the same as if a weight of 40 pounds were fixed at P.

36. Where the load is supposed to be uniform over the two sections $A B$ and $A C$, Fig. 19, suppose that there are 10 cars on each section and that each car averages a load of 20 horsepower. Each section will, then, carry a load of 200 horsepower, which can be taken as concentrated at points O and O' in the center of the respective sections. These centers will be $\frac{1}{2} A B + \frac{1}{2} A C$, or 5 miles apart. The two loads of 200 horsepower concentrated at O and O' in Fig. 19 correspond to the two weights of 20 pounds in Fig. 20, and if we treat the 200 horsepower as weights and find their center of gravity, it will be the center of load or the correct location for the power house. Since the two loads or weights are equal, the center of gravity or load must be at point A, midway between O and O'.

37. Take the case shown in Fig. 21, where $W = 40$ pounds, $W' = 50$ pounds, and $W'' = 10$ pounds; further, suppose that the distance from W to W' is 6 miles; from W to W'', 7 miles; and from W' to W'', 4 miles. Where is the center of gravity situated? First find the center of gravity between weights $W = 40$ and $W'' = 10$, where the distance between centers is 7 miles. This distance of 7 miles must be divided into two parts, such that $W l = W'' l''$, where l and l'' are the distances of W and W'', respectively, from the center of gravity for these two bodies.

To solve the problem graphically, lay out the plan to scale on paper; that is, represent the 7 miles by 7 inches, and so on, and let the sizes of the circles represent the weights, as shown in the diagram. Call L the distance from W to W'', and let the distance from W to the center of gravity to be found, be represented by l; then the distance of W'' from

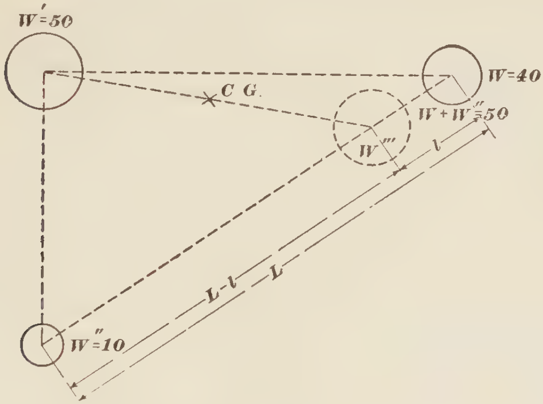


FIG. 21

the center of gravity will be represented by the difference, or $L - l$; and since $Wl = W''(L - l)$, $Wl = W''L - W''l$, or $Wl + W''l = W''L$, and $l = \dfrac{W''L}{W + W''}$. Substituting for the weights and for L the numerical values given, $l = \dfrac{10 \times 7}{50} = 1\tfrac{2}{5}$ miles, or inches on the paper, as the distance of the weight W from the required center of gravity. Since the total distance $L = 7$, the distance from the center of gravity to the center of W'' must be $L - l = 5\tfrac{3}{5}$ miles. On the line joining the centers of W and W'' locate a point that is $1\tfrac{2}{5}$ inches from the center of W; this is the center of gravity sought. The center of gravity between the large dotted circle, representing the combined weights (50 pounds) of W and W'', situated at their center of gravity, and W', which is also 50 pounds, must now be found. Call the dotted circle W'''; since the weights W''' and W' are the

same, it is evident that their center of gravity is midway between them on the line joining their centers, so that it is only necessary to bisect this line in order to find the center of gravity of W' and W''', and hence of the whole system.

38. Conclusion.—The general rule for locating the center of load is as follows: Divide the line of the proposed road into several sections; with a knowledge of the service to be rendered on the road, assign a certain load in horsepower, kilowatts, or amperes to each section. Lay out, to scale, a plan of the road on paper and take the load assigned to each section as concentrated at its middle point; there will then be as many of these points as there are sections, and each point will bear a number designating the load on the section of which that point is the center. The numbers can be considered as representing weights and the center of gravity will be the load center that marks the best location for the power house.

POWER ESTIMATES

39. The problem of deciding what capacity the station generators must have in order to operate a given number of cars on a given road is a complex one, in that it involves conditions peculiar to each case and calls for the use of quantities that must, to a great degree, be determined from data relating to roads of a similar character. Among the factors that must be considered are: Weight of equipment; number of cars; speed of cars; topography of the road (grades, curves, etc.); character of traffic; condition of line and rail return; manner of handling the equipment.

The speed at which the cars run is determined largely by the character of the road; cars in cities may not average more than 8 to 12 miles per hour while on interurban roads the average speed might be as high as 40 or 45 miles per hour. The number of cars to be operated depends on the frequency of the service, the length of the line, and the schedule speed. The best schedule speed and frequency of

service for any given road require a close preliminary study of the district to be served, probable traffic and the returns therefrom, competition that must be met, etc.

40. Weights of Cars.—The size and weight of cars are determined by the traffic. On interurban lines, cars are much heavier than in cities and frequently they approach, in size and weight, those used on steam roads. A modern 40-foot body interurban car complete with motors and controlling apparatus may weigh as much as 65,000 pounds, whereas a city car with 28-foot body will weigh in the neighborhood of 30,000 pounds. Table I gives approximate weights of

TABLE I

WEIGHTS OF CARS

Open Cars					Closed Cars			
Number of Benches	Length Over All		Seating Capacity	Weight of Body and Trucks Pounds	Seating Capacity	Length of Body Feet	Length Over All Feet	Weight of Body and Trucks Pounds
	Feet	Inches						
10	28	8	50	12,000	24	18	26	10,400
12	34	0	60	16,000	34	25	35	18,000
15	40	4	75	25,000	40	28	37	20,000
					44	32	40	28,000

ordinary cars of standard size. In designating the length of closed cars, it is customary to measure between outsides of the bulkheads (end walls) and not over the bumpers. The weights given in Table I do not include the motors, controllers, air-brake equipment, etc. The motors will weigh from 45 to 75 pounds per horsepower (railway-motor rating), the weight per horsepower being smaller for large motors than for small ones. An ordinary controller for a 25-horsepower motor will weigh about 200 pounds, and a complete equipment of two such controllers with the starting resistance, about 500 pounds. This is a light equipment, such as is used for a small 18- or 20-foot car. For a large car equipped with two 65-horsepower motors, the complete electrical

equipment will weigh about 8,300 pounds, of which the two motors constitute over 7,000 pounds. The auxiliary devices, such as controllers, brakes, etc., vary so much in design that it is difficult to give general figures as to the weight of cars complete with equipment. Ordinary closed cars intended for city service will weigh, roughly, .4 ton per foot of over-all length when fully equipped with motors and all auxiliary appliances. For example, a car with 28-foot body, 37 feet long over all, will weigh, fully equipped, $37 \times .4 = 14.8$ tons. Cars intended for interurban traffic, where the speeds are high, will weigh, fully equipped, from .6 to .7 ton per foot of over-all length. In making power estimates, the weight of passengers that should be added to the weight of the car, will not, as a rule, average more than 10 to 15 per cent. of the dead weight of the car.

41. Formulas for Power Estimates.—A number of formulas have been devised for calculating the power required by cars under given conditions, but all of them are only approximate, because several elements modify the power taken. For example, the running gear or roadbed may be in bad condition or there may be excessive friction on some of the curves. Again, the state of the weather may have a marked influence on the power required—a strong head-wind may have a very great effect on the resistance offered to the motion of a car; while it is a well-known fact that cars do not run as easily in cold weather as in warm, because of the increased friction at the journals. As a consequence of all these influences, the effects of which cannot be accurately determined, formulas in which the resistance offered to the motion of a car or train is used must not be expected to give results other than approximate.

42. Force Required to Move Car on Level Track. The force or horizontal effort at the rail head, per ton weight, required to move a trolley car on a level track at a uniform speed is considerably higher than required for cars operated on steam roads, where the track is cleaner and in better condition generally. Steam cars are also much

heavier than ordinary street cars and the effort per ton is less for heavy cars than for light ones.

The effort that must be applied to keep a car in uniform motion on a level track depends on the train resistance at uniform speed and this, in turn, is made up of a number of factors that are more or less difficult to determine and which vary, to a certain extent, with the speed. For example, the train resistance includes the track friction, or the resistance that the wheels encounter in rolling over the slight irregularities in the surface of the track, the friction in the journals, friction of wheel flanges against the rails, air resistance, etc.

If f = resistance, in pounds, per ton on a level track, i. e., horizontal effort at rail head for each ton that the car weighs;

W_t = weight of car, in tons;

F = total pull required;

then,
$$F = f W_t \qquad (1)$$

The case of cars operating at moderate speeds in cities, where the effort per ton may be taken as constant for all speeds at which the cars usually run, will first be considered. For ordinary cases, with cars and track in good condition, a fair average value for f on a level track is 20 pounds.

43. Effect of Grades.—Grades are always expressed as a percentage, but there seems to be considerable confusion as to what this percentage refers. In some cases it relates to the distance actually traveled by the car in ascending the grade; in others, to the horizontal distance. The more general method in dealing with electric railways is to consider the percentage as referring to the actual distance traveled by the car, and it will be so taken in the following calculations. Thus, if a grade is said to be 3 per cent. it means that for every 100 feet traveled along the grade the car rises 3 feet. This simplifies calculations and, as a matter of fact, unless grades are much steeper than those usually met with in practice it makes very little difference, so far as numerical results are concerned, which is taken

because the distance traveled along the grade is practically the same as the horizontal distance.

When a car ascends a grade, the force exerted, in addition to overcoming the various resistances, must be sufficient to lift the weight of the car. Thus, on a 1-per-cent. grade, the car rises 1 foot for every 100 feet traveled. This is equivalent to lifting the weight of the car one one-hundredth of the distance or lifting one one-hundredth of the weight the whole distance. In other words, for each ton (2,000 pounds) that the car weighs, each per cent. grade is equivalent to the addition of $\frac{2000}{100} = 20$ pounds to the effort required on the level, and

$$f_g = f + 20\,G \qquad (2)$$

where f_g = pounds per ton on the grade;

f = pounds per ton on the level;

G = per cent. grade.

EXAMPLE.—If 20 pounds per ton is required to maintain uniform motion of a 10-ton car on a level track, what effort, per ton, will be required on a 5-per-cent. grade?

SOLUTION.—For each per cent. of grade, the force must be increased 20 lb. per ton over the amount required on the level; hence, $f_g = 20 + 20 \times 5 = 120$ lb. per ton. Ans.

44. Horsepower.—When the total force F, in pounds, and the speed S, in miles per hour, are known the horsepower can at once be calculated as follows:

$$\text{Speed, in feet per minute} = \frac{5{,}280\,S}{60}$$

$$\text{horsepower} = \frac{\text{foot-pounds per minute}}{33{,}000} = \frac{5{,}280\,S\,F}{60 \times 33{,}000}$$

or,

$$\text{horsepower} = \frac{S\,F}{375} \qquad (3)$$

If the car is moving up a grade, F must, of course, include the effort necessary to lift the car. This formula gives the horsepower actually used in moving the car; the electrical power supplied will be somewhat greater on account of the electrical losses in the motors and controlling apparatus.

45. The curves shown in Fig. 22 are useful in making approximate determinations of the tractive effort and

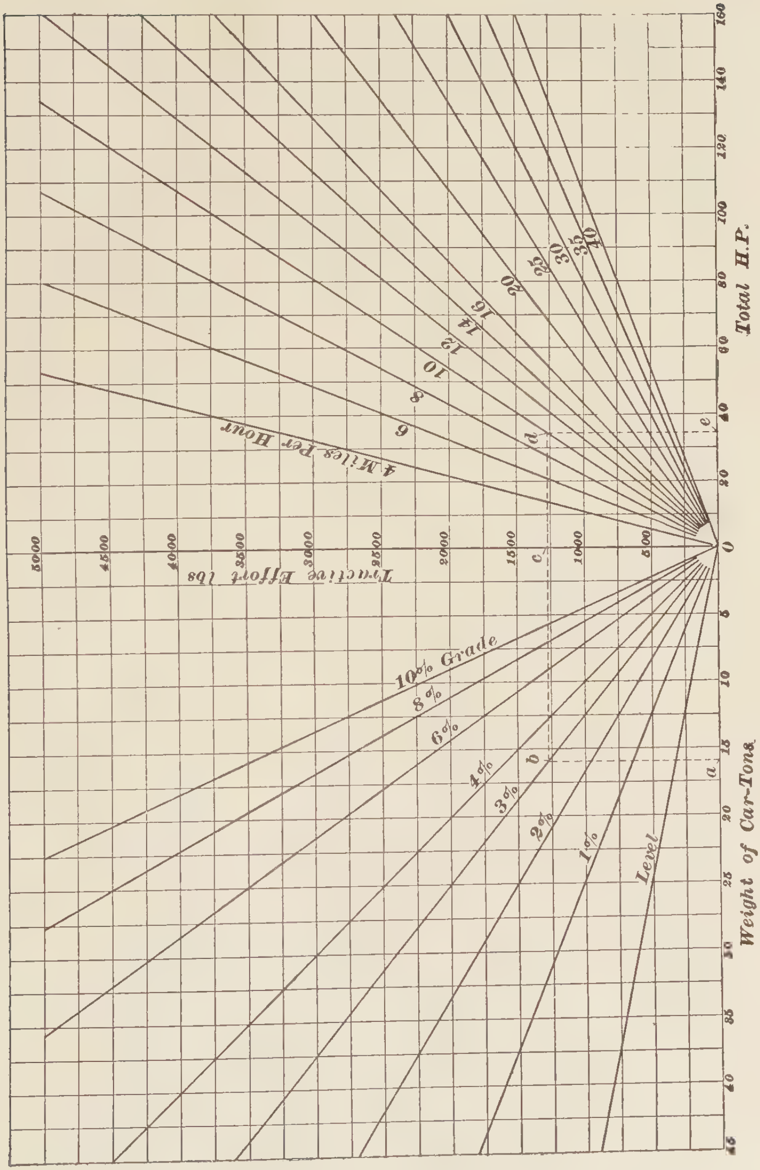

Total H.P.
Weight of Car-Tons
Tractive Effort lbs
4 Miles Per Hour
6
8
10
12
14
16
20
25
30
35
40
10% Grade
8%
6%
4%
3%
2%
1%
Level
a
b
c
d
e
0
20
40
60
80
100
120
140
160
5
10
15
20
25
30
35
40
45
500
1000
1500
2000
2500
3000
3500
4000
4500
5000

FIG. 22

horsepower required under given conditions. They are given by the Westinghouse Company and are based on the assumption that the tractive effort per ton on the level is 20 pounds, and 20 pounds additional for each per cent. grade.

EXAMPLE.—How many horsepower are required to move a car weighing 16 tons up a 3-per-cent. grade at the rate of 10 miles per hour, if the tractive effort is 20 pounds per ton on the level?

SOLUTION.—The tractive effort will be from formula **2**, $f_g = 20 + 20 \times 3 = 80$ lb. per ton and the total tractive effort $F = 16 \times 80 = 1{,}280$ lb. The speed S is 10 mi. per hr., hence, from formula **3**,

$$\text{H. P.} = \frac{10 \times 1{,}280}{375} = 34.1. \quad \text{Ans.}$$

The problem can be solved more rapidly by referring to Fig. 22. First find the point a on a horizontal line to the left of O, corresponding to 16 tons; draw a vertical line at a until it intersects the 3-per-cent. line at b. The height of this line will represent the total tractive effort that can be read off the central vertical scale by drawing a horizontal line across from the intersection b to c. Continue this horizontal until it intersects the speed line corresponding to 10 miles per hour at point d and drop a perpendicular on the base or *H. P.* line from d; $O e$ represents the horsepower required and is read off the horizontal scale, giving 34.1 horsepower, as calculated.

TRAIN ACCELERATION

46. So far it has been assumed that the motion of the cars was uniform. It requires, however, much more power to start a train and get it under headway than to keep it in motion after it has been started. If cars were equipped with motors having a capacity based on calculations relating to uniform motion, they would be too small unless the conditions were such that the stops were very infrequent. In the early days of electric railroading, the motors installed were soon found to be too small, largely because the excess of power required at starting had been overlooked.

47. In order to start a train from rest and bring it up to speed, a certain amount of energy must be expended over and above that necessary to overcome the train resistance. The energy so expended is stored in the train as

kinetic energy. A powerful effort is necessary to accelerate the train, and the effort required in any given case will depend on the weight of the train and the acceleration. In problems connected with train operation, the rate at which the speed of a train is increased (acceleration) or decreased (retardation, or deceleration, as it is sometimes called) is expressed in miles per hour per second. For example, if the acceleration is $1\frac{1}{4}$ miles per hour per second, it means that in each second the speed of the train is increased $1\frac{1}{4}$ miles per

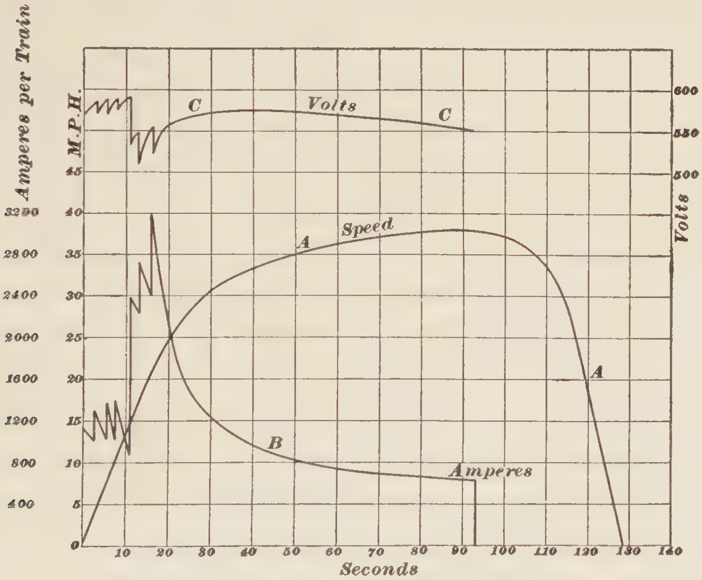


FIG. 23

hour. If the train started from rest, at the end of the first second it would be moving at the rate of $1\frac{1}{4}$ miles per hour, at the end of the second second, at $2\frac{1}{2}$ miles per hour, and so on.

Fig. 23 shows typical curves for an electric train with powerful equipment capable of producing rapid acceleration. Curve A shows the relation between speed and time; B, shows the total current supplied; and C, the voltage. Starting from a standstill, the speed increases at an almost uniform rate up to 25 miles per hour; the curve then bends over and

the increase in speed during a given interval of time, i. e., the acceleration, becomes less until at 37½ miles per hour the curve has become nearly horizontal; the speed is then nearly uniform and the acceleration has become practically zero. After 93 seconds the current is shut off and the train coasts along, by virtue of the energy stored in it, with gradually decreasing speed. The brakes are applied at the latter end of the run and the train is retarded and finally brought to a stop, as indicated by the straight sloping line at the right. When the train is started with all the starting resistance in series, the total current is about 1,100 amperes, and as the resistance is cut out, the current varies, as shown by the notches in the curve during the first 10 seconds; the motors are then thrown in parallel and the total current rises to nearly 2,400 amperes, after which it further increases to 3,200 amperes, as the resistance on the parallel notches is cut out. Up to this point the current in each motor has remained approximately constant and the tractive effort has, therefore, been nearly constant. The train resistance is also approximately constant for moderate speeds with the net result that the speed is almost uniformly accelerated from 0 to 25 miles per hour during the first 20 seconds. The average acceleration during this interval is 1.25 miles per hour per second. As the speed increases beyond 25 miles per hour, the current rapidly diminishes and the tractive effort also diminishes. The acceleration therefore decreases, and when the current has dropped to about 650 amperes the speed has become nearly uniform. The tractive effort is then wholly utilized in overcoming the train resistance; during the acceleration period a large part of the total effort was used in increasing the speed and thereby storing energy in the train, and the remainder went to overcome the train resistance.

48. Force Required for Acceleration.—The total force F_a required to make a car or train increase its rate of speed is easily calculated; it is $F_a = m\,a$, where m is the mass of the train and a the acceleration. $m = \frac{w}{g}$, where w

is the weight of the train and g the acceleration due to gravity; hence, $F_a = \frac{w}{g} a$. If w is expressed in pounds, g in feet per second per second, and a in feet per second per second, then F_a will be in pounds and $F_a = \frac{w}{32.16} a$, since g is equal to 32.16 feet per second per second. Usually, in train calculations, the weight is expressed in tons and the acceleration in miles per hour per second instead of feet per second per second. One mile per hour = 1.467 feet per second and 1 ton = 2,000 pounds. If, then, A is the acceleration in miles per hour per second, the number of feet per second per second will be 1.467 A, and if W_t is the weight in tons, the number of pounds will be 2,000 W_t. The equation will then become $F_a = \frac{2{,}000\ W_t}{32.16}$ $\times$ 1.467 A, or

$$F_a = \frac{W_t A}{.01097} = 91.2\ W_t A \qquad (4)$$

Example.—If an electric car weighs 20 tons, what accelerating force must be exerted to bring the car from a standstill up to a speed of 18 miles an hour in 15 seconds, assuming the acceleration to be uniform during this period?

Solution.—The acceleration A is $\frac{18}{15}$ = 1.2 mi. per hr. per sec. W_t = 20 tons; hence, from formula 4,

$$F_a = 91.2\ W_t A = 91.2 \times 20 \times 1.2 = 2{,}188.8 \text{ lb.} \quad \text{Ans.}$$

From formula 4, the tractive effort necessary to produce an acceleration of 1 mile per hour per second is 91.2 pounds for each ton weight of car. Fig. 24 shows the relation between the acceleration, in miles per hour per second, and the accelerating force, in pounds per ton. It must be remembered that this is in addition to the force required to overcome the train resistance. Again, whenever a train is started there are two kinds of inertia to be overcome: The train must be made to move horizontally and the force required for this acceleration is given by formula 4; also, a certain amount of energy is required to overcome the inertia of the rotating parts, such as armatures, wheels, gears, and axles, and this may amount to 8 or 10 per cent. of the force

given by the formula. The force required to overcome train resistance may be taken as 20 pounds per ton for moderate speeds on a good track, and if the force required to produce acceleration both rotational and linear is 100 pounds per ton for an acceleration of 1 mile per hour per second, the total tractive effort required to speed up the car at this rate will not be far from 120 pounds per ton.

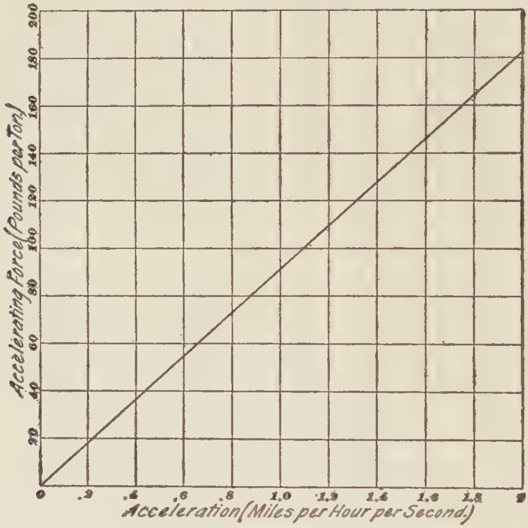


FIG. 24

In city streets, where the speed is limited, it is not necessary or even desirable to accelerate the cars rapidly, but in elevated or underground service, where a large number of trains must be operated at close intervals, they must be started quickly, and the size of the motors will be determined very largely by the energy required for acceleration.

49. Limit of Adhesion.—The maximum effort at the rail head that can be applied to a car is limited by the slippage of the wheels on the track; as is also the possible acceleration and the grade that a car can ascend. The adhesion between wheels and track depends on the weight on the drivers and the coefficient of friction between the

wheels and track. The latter varies greatly with the condition of the rails, being considerably lower for street-car lines where the tracks are liable to be dirty and slippery than for elevated, undergound, or interurban roads where the tracks are cleaner. It also depends on the kind of car wheels, being considerably less for wheels with chilled-iron treads than for those with steel tires. As safe limiting values, the adhesive force may be taken as about 15 per cent. of the weight on the drivers for elevated or interurban roads, and 12 per cent. for street-car roads. Thus, on street-car lines, the maximum tractive effort that can be exerted without causing wheel slippage may be taken as $2,000 \times .12 = 240$ pounds per ton weight on the driving wheels and $2,000 \times .15 = 300$ pounds for elevated or interurban roads. It should be particularly noted that these limiting tractive efforts are per ton weight on the driving wheels. With a small single-truck street car having two motors, all wheels are drivers and the whole weight rests on driving wheels; hence, this style of car is well adapted for hill climbing and running on slippery tracks. With interurban or elevated cars having double trucks and two motors, the weight resting on the drivers will not be more than 55 to 70 per cent. of the total weight, thus making the limiting tractive effort from 165 to 210 pounds per ton weight of car. With cars having double trucks with four motors, one on each axle, the whole of the weight is on drivers; hence, four-motor equipments are desirable for roads operating double-truck cars in hilly localities. For interurban roads, the grades are usually quite moderate and two-motor equipments give sufficient adhesion.

Let f' = force, in pounds per ton weight of car to start car on level;
G = grade expressed as percentage;
W_t = weight of car, in tons;
a = percentage of weight on drivers, expressed as a decimal;
b = ratio of adhesive force to weight on drivers expressed as a decimal.

Then,

Total weight on drivers, in pounds . . . $= 2{,}000\ a\ W_t$

Total adhesive force . . . . $= 2{,}000\ a\ W_t\ b$

Total force required for starting on grade $G = f'\ W_t + 20\ G\ W_t$

Each per cent. grade requires 20 pounds per ton additional effort. When the grade is such that the tractive effort required to start on it is just sufficient to produce wheel slippage, we must have $2{,}000\ a\ W_t\ b = f'\ W_t + 20\ G\ W_t$, and

$$G = \frac{2{,}000\ a\ W_t\ b - f'\ W_t}{20\ W_t} = \frac{2{,}000\ a\ b - f'}{20} \qquad (5)$$

About 70 pounds per ton is a fair value for the effort f' required to start a car on the level under ordinary conditions; if, however, the acceleration is very rapid, the effort during the time that the car is gaining headway may be much higher than this and the acceleration obtainable may therefore be limited by the wheel slippage.

Example.—If 65 per cent. of the weight of a car rests on the drivers and if the ratio of the adhesive force to the weight on the drivers is 15 per cent. what is the maximum grade that the car can start on without wheel slippage, assuming that it requires an effort of 70 pounds per ton weight of car to start the car on the level?

Solution.—Using formula **5**, we have $a = .65$, $b = .15$, and $f' = 70$; hence, $G = \frac{2{,}000 \times .65 \times .15 - 70}{20} = 6.25$; i. e., slippage will occur if the grade exceeds 6.25 per cent. Ans.

TRAIN RESISTANCE

50. In all that has so far been said regarding power calculations, the tractive effort has been taken as 20 pounds per ton regardless of the speed, weight, or shape of the cars. This gives fairly close results for light single cars operated at moderate speeds, under the conditions usually met in city streets, but for heavy single cars or trains operated at high speeds, as used in the heavier kinds of electric traction, it is not safe to assume a fixed value for the train resistance. At low speeds and with heavy cars the effort per ton may be considerably under 20 pounds, and at high speeds it will be greater.

The subject of **train resistance** is a complicated one, because the resistance depends on a number of quantities, which vary more or less with the speed. The air friction increases approximately as the square of the speed and is dependent in a large measure on the shape of the front of the cars and on the area of the exposed surface. On account of the difficulty of determining the amount of the different resistances and their relation to the speed of the train, no formula has yet been established for calculating the tractive effort that must be exerted to move electric trains under widely varying conditions; and from the nature of the case, it is doubtful if any generally applicable formula can be obtained. A number of formulas have been devised that are reasonably accurate, provided that their use is limited to cases where the conditions correspond to those existing during the tests on which the formulas are based. The object here is simply to point out two or three formulas that have been proposed and to show, to some extent, the quantities on which the resistance depends and the amount of resistance due to each. Formula **6**, given below, is due to Mr. W. N. Smith,* and has been found to give results that agree quite closely with tests made on cars weighing from 28 to 32 tons operating at schedule speeds varying from 16 to 35 miles per hour, the maximum speeds during the runs varying from about 27 to 44 miles per hour. The formula is

$$f = 3 + .167\,S + .0025\,\frac{A\,S^2}{W_t} \qquad (6)$$

where f = train resistance, in pounds per ton;
S = speed, in miles per hour;
A = cross-section of car, in square feet;
W_t = weight of car, in tons.

For example, the resistance offered to a 40-ton train moving at the rate of 30 miles per hour and having a cross-sectional area of 100 square feet would be $f = 3 + .167 \times 30$

*Transactions American Institute of Electrical Engineers, Vol XXI, No. 10.

$+ .0025 \times \frac{100 \times 30^2}{40} = 13.64$ pounds per ton. With heavy trains, the train resistance per ton weight of train is less than with light trains.

51. As an example of the resistance of electric trains obtained from actual tests, the experiments of Wm. W. J. Davis* may be cited. These were made with a 37-ton electric locomotive hauling passenger cars of standard type weighing 25, 35, and 45 tons. The number of cars per train was varied from 1 to 5, and the influence of the size of the cars and the weight of the train on the resistance per ton could thus be noted. The curves in Fig. 25 give the results obtained with 25-ton cars; those in Fig. 26 the results obtained with 45-ton cars; these show that the resistance per ton weight is much greater with light than with heavy trains. In Fig. 25, a single-car train at 60 miles per hour offers a resistance of about $58\frac{3}{4}$ pounds per ton, whereas, with a two-car train at the same speed, the resistance is but 39 pounds per ton. The journal friction in case of the 25-ton cars is 8 pounds per ton for all speeds; with the 45-ton cars, the journal friction is 5 pounds per ton. In Figs. 25 and 26, the constant journal friction is represented by the vertical dotted line. The friction due to unevenness in the track is taken proportional to the speed, and in these tests was found to be

$$f' = .13\,S \qquad \textbf{(7)}$$

where f' = track friction;

S = speed, in miles per hour.

The track friction is represented by the slanting dotted lines. That is, the distance between the vertical dotted line and the track-friction line at any given speed represents the track friction at that speed, and the distance between the track-friction line and the vertical passing through *0* represents the journal friction and track friction combined.

*Street Railway Journal, Vol. XIX, No. 18.

At a speed of 35 miles per hour, the track friction would be $f' = .13 \times 35 = 4.55$ pounds per ton. Hence, the distance between the two dotted lines at the point corresponding to a speed of 35 miles per hour is equivalent to

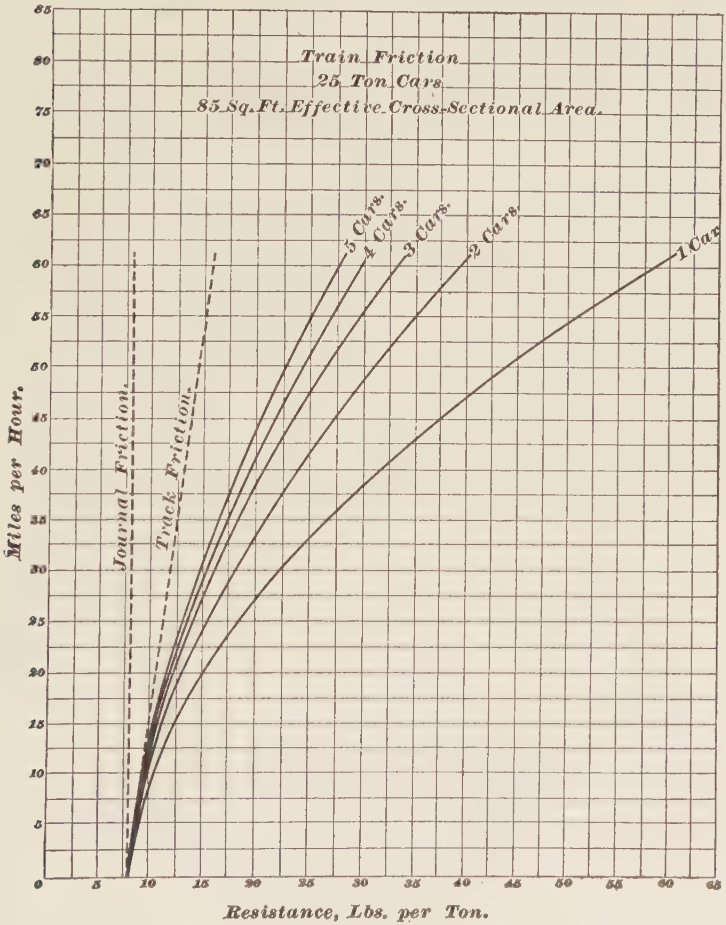


FIG. 25

4.55 pounds per ton. The full-line curves represent the total resistance per ton for trains of 1, 2, 3, 4, and 5 cars. The horizontal distance between the dotted slanting line and

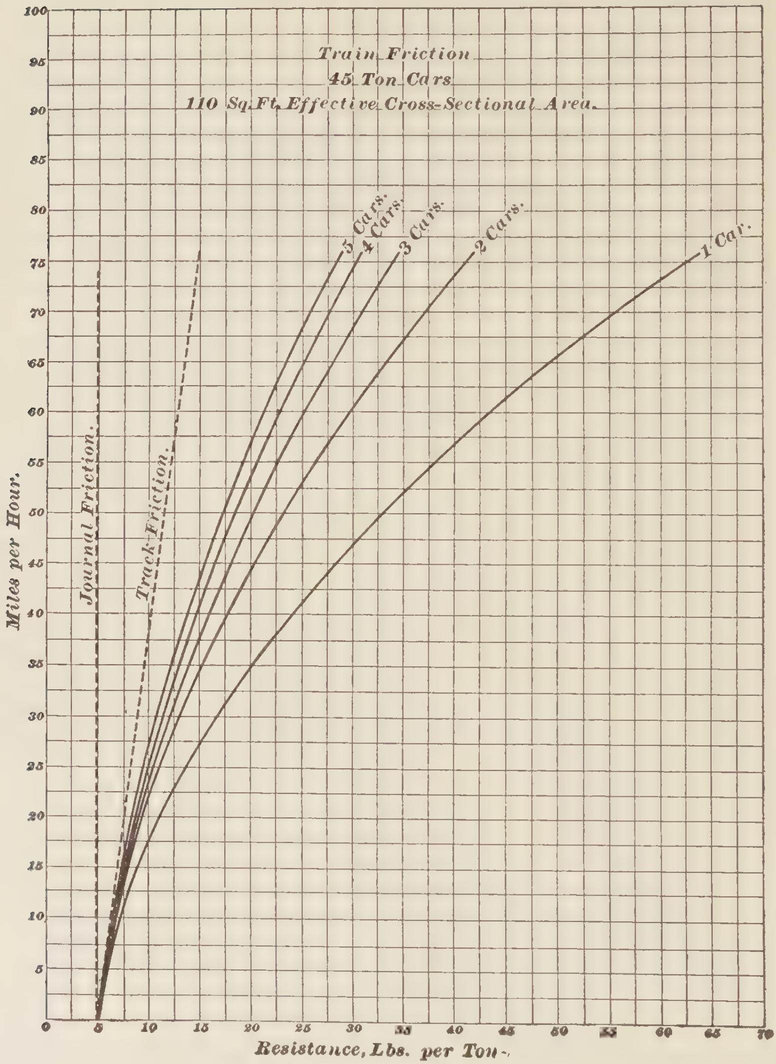

Train Friction
45 Ton Cars
110 Sq. Ft. Effective Cross-Sectional Area.
5 Cars.
4 Cars.
3 Cars.
2 Cars.
1 Car.
Journal Friction.
Track Friction.
Miles per Hour.
Resistance, Lbs. per Ton.

FIG. 26

the curved lines represents the air resistance for trains made up of different numbers of cars. With a single-car train at a speed of 35 miles per hour, the air friction is nearly 16 pounds per ton. and the resistance increases rapidly with increasing speeds. The effect of air resistance is not as pronounced with heavy trains as with light trains. These experiments indicate that it is more economical, as regards power consumption, to operate the cars in trains than singly, especially at high speeds.

52. From these experiments Mr. Davis has derived the following formulas for obtaining the tractive effort for heavy electric trains:

For 25-ton cars having a cross-sectional area of about 85 square feet,

$$f = 8 + .13\,S + \frac{.0035\,A\,S^2}{W_t}[1 + .1(n - 1)] \qquad (8)$$

For 45-ton cars having a cross-sectional area of about 110 square feet,

$$f = 5 + .13\,S + \frac{.0035\,A\,S^2}{W_t}[1 + .1(n - 1)] \qquad (9)$$

where f = train resistance, in pounds per ton;
S = speed, in miles per hour;
A = cross-sectional area of car, in square feet, including area bounded by wheels and truck;
W_t = total weight of train, in tons;
n = number of cars in train including leading car or locomotive, if an electric locomotive is used.

In formula **6**, the constant journal friction is taken at 3 pounds per ton; this is rather low for light cars, being less than half that shown by the Davis tests for 25-ton cars. Formula **6** is, however, intended chiefly for calculations relating to heavy cars.

POWER CONSUMPTION TESTS

INTERURBAN ROADS

53. Tests made on cars in every-day operation afford the most reliable means of estimating the probable amount of power required for a given service. Such tests include observations of the power, speed, time, voltage, current, grades, curves, etc.; in fact, everything that is liable to influence the power consumption. Some very elaborate tests of this character have been made and with regard to interurban roads one of the most complete is that conducted by Mr. Clarence Renshaw on the system of the Union Traction Company, of Indiana.* The figures here given relate to tests made on this road with cars having 40-foot bodies, weighing 63,000 pounds, and equipped with two 150-horsepower motors mounted on the forward truck. The power consumption was measured for both limited and local service so that the effect of stops could be determined. In local service, the average speed for the whole run, 56.5 miles, was 22.6 miles per hour, but part of the run was through cities where the speed had to be reduced. Outside the cities, the speed on local service averaged 26.6 miles per hour. In limited service, the cars averaged 28.3 miles per hour for the whole run and 35.3 miles per hour leaving out the slow running in the cities. The speed between stations frequently rose to 40 and 45 miles per hour, and on one part of the road reached 60 miles per hour. Most of the grades were less than 2 per cent., but a few short ones were as high as 3 per cent. The weight of the car with passengers varied on the different trips, but was usually from 34 to 34.5 tons. The power consumption, as indicated by the average of a large number of wattmeter readings, is given in Table II.

From these figures, it would be safe, in making a preliminary estimate on a road of the same general character as this, to allow from 70 to 75 watt-hours per ton-mile for

*Street Railway Journal, Vol. XX, No. 14.

limited service and 85 to 90 watt-hours per ton-mile for local service.

It is interesting to note that very complete tests made with 25-ton cars on a different interurban road—the Dayton and Northern Traction Company—give results that agree quite closely with those in Table II. The average power consumption for a number of regular trips with the speed varying from 8 to 29 miles per hour, was 2.16 kilowatt-hours per car mile or 86.4 watt-hours per ton-mile. The average consumption for a number of test runs, with speeds varying from 19 to 27.5 miles per hour, was 1.96 kilowatt-hours per car mile or 78.4 watt-hours per ton-mile. The greatest power consumption was for a short run of 1.46 miles at the slow speed of 8 miles per hour, when the consumption was 148 watt-hours per ton-mile.

TABLE II

POWER CONSUMPTION OF CARS

(*Interurban Road*)

Class of Service	Kilowatt-Hours per Car Mile	Watt-Hours per Ton-Mile
Local service, outgoing trips	2.24 to 2.78	66.7 to 81
Local service, return trips	2.62 to 2.31	77 to 89.5
Local service, average for six round trips .	2.62	76.6
Limited service, outgoing trips	2.1	58.7
Limited service, return trips	2.31	71.6

54. Influence of Stops.—It seems strange at first glance that the slow-speed local service (Table II) should show a power consumption greater than that of the high-speed limited service, but the explanation is found in the relatively large number of stops necessitated by the local service. Every time a car is started, a certain amount of energy is wasted in the starting resistance and energy is also required for acceleration. The greater part of the latter is usually wasted at the brake shoes when the car is brought to a stop. Thus, if the stops are very numerous the power

consumption per ton-mile is considerably increased. Tests on the Union Traction Company's road showed that, on the average, the local service required 15 per cent. more power per trip than the limited service.

The following comparison of a number of runs shows clearly the increased power consumption due to stops.

Service	Stops	Watt-Hours per Ton-Mile	Time for Trip	
			Hours	Minutes
Limited . . .	4	71.6	2	
Local	31	83.3	2	36
Local	44	89.5	2	53

It must not be inferred that in all cases local service with numerous stops requires more power than high-speed service with few stops; in fact, the contrary is often the case. In this instance the schedule speed on limited service is not very high (35.3 miles per hour), but with higher schedule speed the energy per ton-mile for limited service would be greater than that for local service and might easily be from 90 to 110 watt-hours. When the average speed is over 35 miles per hour a comparatively slight increase in speed involves a large increase in power because of the great increase in air resistance.

55. Current.—In the above tests, the cars took at starting from 200 to 250 amperes and when the motors were placed in parallel the current rose as high as 250 to 330 amperes. These large currents, however, only lasted for short intervals.

56. Voltage.—The average line voltage, when the car was running, was 454 volts, but the average voltage at the terminals of the motors was very much lower because sometimes the motors were in series, with resistance, sometimes in series without resistance, or in some cases no voltage at all was applied to them, as, for example, when the car was

coasting or when the brakes were applied. The average voltage per motor was thus about 237 volts.

57. Conclusion.—The application of the data here given can best be illustrated by working an example.

EXAMPLE.—An interurban electric road is to operate ten cars weighing 30 tons each when loaded. Six of these are to run on local service and four on limited service, the average speed on local service being 20 miles per hour and on limited service 32 miles per hour. Estimate the approximate capacity of the generating plant, assuming that the total loss between generators and cars is 18 per cent. of the delivered power.

SOLUTION.—Referring to the figures given in Art. **53**, the average power consumption, in watt-hours per ton-mile, may be taken at, say, 72.5, taking the average of 70 and 75 for the limited cars, and 87.5 for the local service. In 1 hr., therefore, the total number of watt-hours supplied would be:

For local service,	$6 \times 30 \times 20 \times 87.5 =$	315,000 watt-hours
For limited service,	$4 \times 30 \times 32 \times 72.5 =$	278,400 watt-hours
	Total,	593,400 watt-hours.

Since the energy supplied to the cars in 1 hr. is 593,400 watt-hours it follows that the power is 593,400 watts, or 593.4 K. W. The loss between the generating station and the cars is $593.4 \times .18 = 106.8$ K. W. This represents the loss in lines, third rail, rotary converters, and transformers. The average output of the station will therefore be $593.4 + 106.8 = 700.2$ K. W. On an interurban system, where comparatively few cars are operated, the fluctuations in load are very great and the maximum load is usually from 1.5 to 2 times the average load. Also, considerable power is required for lighting and heating cars and lighting stations. In this case, therefore, the machinery should be capable of furnishing at least 1,000 K. W., and in order to insure against shut-downs it would be advisable to install two generating units of 1,000 K. W. each, or at least three generators of 500 K. W. each, two being operated in parallel under ordinary conditions and the third kept as a reserve. Ans.

CITY ROADS

58. The power consumption per ton-mile is greater for city roads than for interurban lines. The cars are lighter and the tractive effort per ton greater, the stops are much more frequent, and in most cases the track is not as clean or in as good condition. Also on account of the slow speed and numerous stops, considerable power is wasted in the

TABLE III

POWER CONSUMPTION OF CARS

(City Road)

Type of Motor	Horsepower of Each Motor (Railway Rating)	Number of Motors per Car	Average Current Amperes	Maximum Current Amperes	Average Pressure Volts	Average Watts	Watt-Hours per Car Mile
Westinghouse, No. 3 . .	30	1	13.3	60	538	7,155	812
Westinghouse, No. 3 . .	30	1	26.0	60	519	13,494	1,180
Westinghouse, No. 3 . .	30	2	37.7	160	470	17,719	1,690
Westinghouse, No. 3 . .	30	2	30.6	125	470	14,382	1,249
Westinghouse, No. 3 . .	30	2	20.3	80	470	9,541	864
Westinghouse, No. 3 . .	30	2	17.0	72	474	8,058	690
Westinghouse, No. 3 . .	30	2	17.8	65	488	8,686	781
Westinghouse, No. 3 . .	30	2	18.0	88	494	8,892	804
Westinghouse, No. 3 . .	30	2	20.1	75	498	10,010	1,062
Westinghouse, No. 3 . .	30	2	17.3	70	519	8,979	814
Westinghouse, No. 3 . .	30	4	38.9	175	486	18,905	1,636
Westinghouse, No. 3 . .	30	4	41.2	150	446	18,375	1,895
Westinghouse, No. 49 . .	35	2	34.0	125	452	15,368	1,479
Westinghouse, No. 49 . .	35	2	27.0	118	444	11,988	1,034
Westinghouse, No. 49 . .	35	2	10.6	75	494	5,236	539
Westinghouse, No. 49 . .	35	2	18.7	70	492	9,200	798
Westinghouse, No. 49 . .	35	4	43.5	170	471	20,489	1,924
Westinghouse, No. 49 . .	35	4	44.8	170	536	24,013	2,128
Westinghouse, No. 38 B .	50	2	50.8	185	435	24,638	1,845
Westinghouse, No. 38 B .	50	2	47.4	200	478	22,657	1,845
Westinghouse, No. 56 . .	60	4	110.4	420	471	51,998	3,778

EQUIPMENT C

Road			Number and Size of Cars							Mot	
	Kind of Road	Miles of Single Track	Number of Cars	Number of Open Cars	Number of Closed Cars	Size of Open Cars	Length of Closed Cars Over All	Length of Closed Cars Between Bulkheads	Other Rolling Stock in Regular Operation	Number per Car	Type or Horse-power (Railwa
A	Inter-urban	28.25	13		6		42 ft. 3 in.		1 double-truck work car; 6 single-truck flat cars	4	* W. No
B	Inter-urban	90	20		20		60 ft.	50 ft.		4	† G. E 75 H
C	Small city	9.16	40	24	15		18 ft.		1 combined sprinkler and snow plow	2	3
D	City	116.8	268			9 and 10 bench		20 and 21 ft.		2	G. E 38 H
E	Inter-urban	39.5	8		8		44 ft. 6 in.		1 freight car, 42 ft. long	4	50 H
F	City	83	122	39	70	8 and 10 bench		18 ft. 20 ft. 28 ft.		18 ft. 20 ft. and open cars, 2 motors; 28-ft. cars, 4 motors	W. H. N W. H. N W. H. N W. H. N
G	Inter-urban	34	10		10		45 ft.			4	G. E
H	City and sub-urban	34	9		9		6 suburban, 49 ft. 5 in.	3 city cars, 18 ft. body		Suburban 4 City 2	75 H 25 H
I	City	63.37	57		57		40 ft.		1 electric locomotive	4	
J	Inter-urban	66.6	15	3	12	15 bench	50 ft.		1 35-ton electric locomotive for freight	4	50 H
K	Inter-urban	26.2	6		6		51 ft.	43 ft.		4	G. E
L	Inter-urban	40	13		13		52 ft.	42 ft.		2	150 H

* W. H (Westingh

	Generators		Engines			Boilers			Remarks
Miles per Hour	Number of Generators	Output per Generator Kilowatts	Number of Engines	Indicated Horsepower per Engine	Type of Engine	Number of Boilers	Horsepower per Boiler (Boiler Rating)	Type of Boiler	
	2	400	2	500	Horizontal cross-compound, direct-connected	3	300	Horizontal water-tube	Flat cars not equipped with motors. A. C. distribution from substations
	2	800	2		Horizontal cross-compound, direct-connected	6	500	Horizontal water-tube	A. C. distribution to four substations each containing two 300-kilowatt rotary converters
20	2 2	150 200	2 2	175 300	Tandem compound, belted; tandem compound, direct-connected	2 2	150 300	Horizontal return tubular; horizontal water-tube	D. C. distribution used throughout
18	6	700	6	750	Tandem compound, vertical	8	500	Horizontal water-tube	Combined water-power and steam plant. Each generator driven either by engine or water wheels giving 1,200 horsepower under 25-foot head
	2	250	2	400	Horizontal compound, direct-connected	3	260	Horizontal water-tube	A. C. distribution. Freight car has same motor equipment as passenger cars
	1 1 2	200 225 800	1 1 2	300 300 1,200	Vertical cross-compound, belted; horizontal cross-compound, direct-connected	6	300	Vertical water-tube	D. C. transmission. Boosters used on long feeders. Three storage-battery substations
	2	350	2	500	Direct-connected	4	175	Return tubular	D. C. transmission. Power house located near center of road
	2	400	2	625	Horizontal cross-compound, direct-connected	4	310	Horizontal water-tube	D. C. transmission. Distant parts of line supplied through booster feeders
	2	1,000	2		Horizontal cross-compound	6	450	Horizontal water-tube	D. C. transmission
30	2 1	540 360	2 1	750 500	Tandem compound, direct-connected	4	300	Vertical water-tube	A. C. transmission
	3	400	3	600	Cross-connected simple engines	6	300	Horizontal water-tube	Cars equipped with multiple-unit control. Each generator driven by a pair of 300-horsepower cross-connected simple engines
ess l	2	1,250	2	2,000	Vertical cross-compound, direct-connected	5	400	Horizontal water-tube	Double-current generators are used (600-volt, direct current, 360-volt alternating current)

E. (General Electric),

starting resistance. The average power consumption per ton-mile will seldom be less than 90 watt-hours and in most cases will exceed this amount; 110 to 120 watt-hours may be taken as a fair approximation. The watt-hours per car mile will usually lie between 750 and 1,500 for single-truck cars with two motors of 30 or 35 horsepower, and between 1,500 and 2,500 for double-truck cars with four motors of 30 or 35 horsepower. Table III shows the results of tests on a number of different runs with motors of the sizes ordinarily used for operation in cities. The first two cars are equipped with a single motor with rheostatic control; all the others have series-parallel control.

EXAMPLES FOR PRACTICE

1. If 25 pounds per ton is required to propel a 30-ton car on a level track, what total force must be applied to propel the car up a 2-per-cent. grade? Ans. 1,950 lb.

2. If a total force of 500 pounds is required to propel a car at the rate of 15 miles per hour, how many horsepower are expended in moving the car? Ans. 20 H. P.

3. (*a*) If a car weighs 25 tons, what force must be applied to produce an acceleration of 1.25 miles per hour per second? (*b*) What must be the total force applied to produce the acceleration and overcome the train resistance as well, assuming that the latter amounts to 20 pounds per ton weight of car? Ans. $\begin{cases} (a) \text{ 2,850 lb.} \\ (b) \text{ 3,350 lb.} \end{cases}$

4. A certain car has 60 per cent. of its weight resting on the driving wheels and the adhesive force between track and rail is 15 per cent. of the weight on the drivers. A force of 75 pounds per ton weight of car is necessary to start the car from rest. What is the steepest grade on which the car can be started without slippage of the wheels on the tracks? Ans. 5.25 per cent.

EXAMPLES OF RAILWAY EQUIPMENT

59. In order to show the character of station equipment used for the operation of a number of typical railways, Table IV is here inserted. In all cases, except *K*, compound condensing engines are used; road *K* is situated in a coal-mining region where fuel is cheap and water suitable for

condensing purposes scarce; hence, simple non-condensing engines are used. On all the roads except *G*, water-tube boilers are used; this type of boiler is almost essential in railway work because the demand for power fluctuates greatly and the steaming of the boilers must respond quickly to the changes in load. Also, they must admit of forcing beyond their regular capacity in cases of emergency.

COST OF POWER

60. The cost of generating power in electric-railway plants varies greatly, as one would naturally expect, because it includes many items that are subject to wide fluctuation. In fact, in even the same station the cost will be higher during some months than others. Table V, from the Street Railway Review, gives figures relating to the cost of generating power in some stations of considerable size. It should be noted that the total cost covers only the items of fuel, labor, supplies, water, and repairs. It does not allow for interest on the investment, or depreciation of the plant. The cost per kilowatt-hour, not including interest and depreciation, will lie between .65 cent and 1 cent for many steam-power stations. In a large number of plants the total cost, including interest, etc., will lie between 1 and 2 cents per kilowatt-hour and in some of the largest plants it may be somewhat below 1 cent per kilowatt-hour. When power is sold from one railway company to another a common charge is 3 cents per kilowatt-hour. Every station switchboard should be equipped with at least one recording meter for measuring the station output, and it is a good plan to provide two meters so that one can operate while the other is being calibrated. In case only one instrument is used, it should be checked at frequent intervals to see that its indications are correct.

61. Station Record.—In order that the cost of generating power in a station may be accurately known, it is necessary to keep a complete record of the various elements

TABLE V

COST OF POWER FOR ELECTRIC RAILWAYS

(Output Measured by Wattmeter in Each Case)

Station	Month	Monthly Output Kilowatt-Hours	Cost of Electrical Output per Kilowatt-Hour. Cents						Gallons of Cylinder Oil per 10,000 Kilowatt-Hours	Gallons of Lubricating Oil per 10,000 Kilowatt-Hours	Pounds of Water per Pound of Coal	Pounds of Fuel per Kilowatt-Hour	Price of Fuel per Ton of 2,000 Pounds	Kind of Fuel
			Fuel	Labor	Supplies—Oil, Waste, Etc.	Water	Repairs	Total						
1	Jan.	2,455,060	.322	.111	.029	.029	.044	.535	2.62	.848	10.83	2.45	$2.63	Bituminous
1	Feb.	2,511,280	.334	.114	.036	.027	.025	.536	2.64	.829	10.05	2.54	2.63	Bituminous
1	Mar.	2,097,160	.337	.123	.037	.030	.040	.567	2.84	.987	11.21	2.55	2.64	Bituminous
1	Apr.	2,158,660	.344	.129	.039	.032	.043	.587	2.98	.722	11.37	2.61	2.64	Bituminous
5	Jan.	2,445,161	.408	.110	.013	.011	.016	.558	2.18	1.31	5.51	4.10	1.99	Bituminous
5	Feb.	2,512,125	.389	.116	.014	.008	.011	.538	2.50	1.08	5.32	3.89	2.00	Bituminous
5	Mar.	2,352,698	.405	.126	.018	.011	.016	.576	2.52	1.70	5.15	4.33	1.87	Bituminous
5	Apr.	1,887,029	.347	.149	.020	.011	.036	.563	3.91	1.14	5.22	4.22	1.65	Bituminous
6	Nov.	827,008	.712	.198	.033		.067	1.010				2.35	.943*	Oil
6	Dec.	810,728	.709	.198	.024		.070	1.001				2.36	.937*	Oil
6	Jan.	643,482	.680	.251	.038		.185	1.154				2.24	.945*	Oil
6	Feb.	494,000	.655	.282	.037		.181	1.155				2.25	.905*	Oil
6	Mar.	562,574	.761	.266	.031		.059	1.117				2.42	.976*	Oil
6	Apr.	616,634	.628	.236	.030		.095	.989				2.31	.843*	Oil

* Price of oil per barrel.

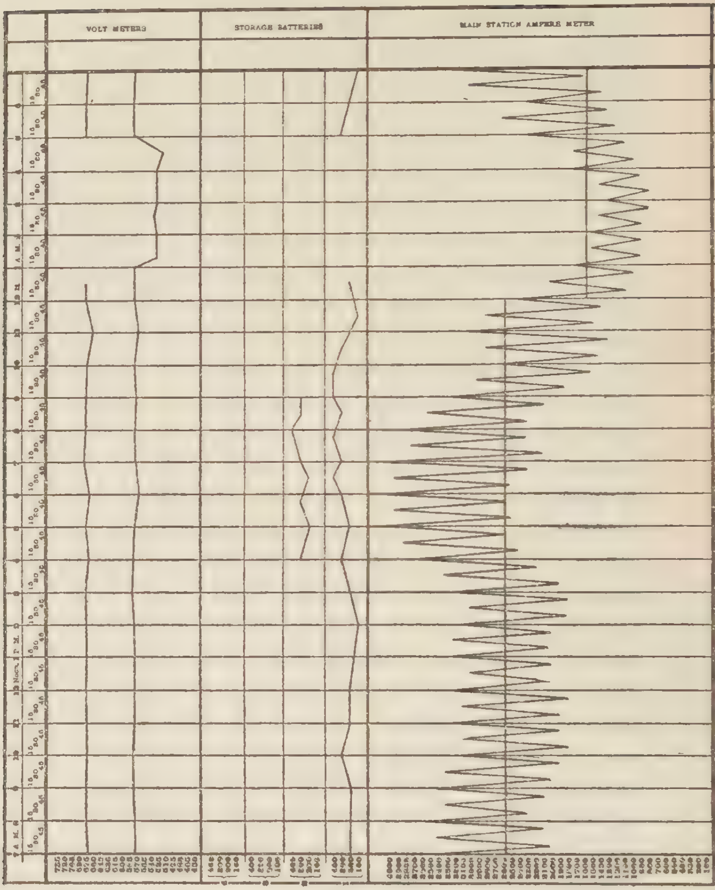
entering into the cost, together with the total output of the station. By dividing the total cost of operation per day by the total output in kilowatt-hours, as indicated by the recording instruments, the cost per kilowatt-hour is obtained. Fig. 27 shows a form of daily chart that gives all the necessary information in a very compact manner and indicates the actual readings as taken for a 24-hour run of the Camden and Suburban Railway Company's power station. This is a direct-current plant throughout. Distant parts of the system are supplied through boosters, and on the date represented by the chart two storage batteries were also in operation. The switchboard is equipped with high-potential and low-potential bus-bars. The full size of the chart is 23½ inches by 25 inches, and in the upper part are shown: first, the voltmeter readings on both high- and low-potential bus-bars; second, the storage-battery current; third, the readings of the main-station ammeter. All these readings are taken at 15-minute intervals and the heavy lines represent the average current from 7 A. M. until midnight, and from midnight to 7 A. M. The vertical dotted lines show the length of time and the hours during which each booster, generator, boiler, etc. was in use; feedwater temperatures, vacuum-gauge readings, etc. are also recorded as shown. In the lower left-hand part of the chart, the readings of the recording meters are given by marking the position of the hands on the printed dials. For the 24 hours, the total output as indicated by the two main recording instruments was 30,225,000 watt-hours, or 30,225 kilowatt-hours; the dial readings are indicated by the figures immediately above each dial, and they must be multiplied by the meter constant 5 and three ciphers added to the result to give the watt-hours, as shown at the bottom of the chart. The remainder of the chart is self-explanatory. The total cost of operation, including repairs, for the 24 hours is $200.17, making the cost per kilowatt-hour $.0066, or .66 cent.

From 7 A. M. *Friday Dec 9 1904*
To 7 A. M. *Saturday Dec 10 1904*

Date of completed reading *Saturday Dec 10 1904*

Camde… Ra…

POWER H…



24 HOURS	7 A. M. – Midnight	12 Midnight – 7 A. M.	CHARGE		DISCHARGE	24 HOURS	7 A. M.–12 Midnight
Max. Volts 575	575	575		Max. Amps.		Max. Amps. 4000	4000
Min. " 510	555	510		Min. "		Min. " 800	1400
Avg. " 560	569	544		Avg. "		Avg. " 2249	2563

HOUSE LIGHTING Watt Meter

TIME 7 A. M.

TIME 7 A. M.

28524300 W. Hs.
28499700 W. Hs.
Reading 24600 W. Hs.

Wood Lynne Lights Watt Meter

TIME 7 A. M.

TIME 7 A. M.

W. Hs.
W. Hs.
Reading W. Hs.

No. 1 Booster Watt Meter

TIME 7 A. M.

TIME 7 A. M.

W. Hs.
W. Hs.
Reading W. Hs.

MAIN STATION WATT… Upper Bar

TIME 7 A. M. 171939

TIME 7 A. M. 181898

9 099 90000 W. Hs.
8 9 21 95 000 W. Hs.
Reading 1 7 2 95 000 W. Hs.

20…
30…
Reading …

Suburban
y Co.

Approved W. Harrington Vice President and General Manager
O. A. Johnson Chief Engineer

DAILY CHART

WEATHER REPORT			
Time	9 o'clock	1 o'clock	5 o'clock
Day	Cloudy	Clear	Clear
Night	Clear	Clear	Clear

TIDE	
High	2.25 AM
Low	9.00 AM
High	2.01 AM
Low	10.08 PM

NERATORS | BOILERS | FEED PUMPS | CONDENSERS | REMARKS

No. 1 Vac.	No. 2 Vac.	Hot Well Temp.	Feed Water Temp.	Steam Press.
26	26	119	197	115
26	26	117	195	115
26	26	108	203	115
26	26	112	213	115
26		110	195	115
26		109	180	115
		86	92	115
		117	125	115
		95	100	115
		107	115	115
		97	100	115
		114	192	115
	26	92	98	115
	26	119	200	115
26	26	120	197	115
26	26	122	195	115
26	26	120	194	115
26	26	[illegible]	200	115
26	26	120	200	115
26	26	117	200	115
26	26	115	200	115
26	26	108	260	115
26	26	109	200	115
26	26	111	200	115
26	26	115	194	116
26	26	117	190	115
26	26	107	200	115
26	26	119	195	115
26	26	113	195	115
26	26	118	166	115
26	26	117	195	115
26	26	119	192	115
26	26	118	190	115
26	26	116	200	115
26	26	112	210	115
26	26	109	208	115
26	26	118	200	115
26	26	122	202	115
26	26	109	206	115
26	26	118	200	115
26	26	114	198	115
26	26	113	200	115
26	26	116	208	115
26	26	114	200	115
26	26	110	201	115
26	26	110	200	115
26	26	108	201	115
26	26	113	198	115

% Ash 14.2 %
Cost of operation per K.W.H.
.0066

BREAKERS OUT

Br'k'r No.	Cable No.	Time Out	Time In	Reported Cause of Trouble
5	6	2.16	2.16	Q. In.
5	5	5.35	5.35	Q. In.
7	7	6.36	6.36	Q. In.
7	7	6.40	6.40	Q. In.

COAL REPORT

Price per ton $2.60
Discharging price per ton .10
Total 2.70
Name of Mine
Dealer Puritan Coal Mining Co.

Coal in stock previously reported 4298.90 Tons
Coal received this date
Total 4298.90
Coal used this day 56.67
Balance in stock 4242.23

	DAY	NIGHT
Coal, hard lbs.		
" soft	74321	52632
Total	74321	52632

Grand total 56 tons 1513 lbs.
Ashes—Day 9926
" Night 8120
Total Ash 18027
Coal per K. W. Hr. 4.2
" " E. H. P. 73.5

	DAY	NIGHT
Cost, hard coal		
" soft coal	89.58	63.44
Total	89.58	63.44

Total cost of coal $153.02
Cost per K. W. Hr. .0051
" " E. H. P. .0809

OPERATING FORCE

DAY, 12 Hours.		Rate.	NIGHT, 12 Hours.		Rate.
Engineer	Fischer	4.17	Engineer	Griffith	2.67
Electrician	Coyne	1.75	Electrician		
Oiler	Finch	1.83	Oiler	Naylor	1.83
Mechanic	Perry	1.75	Mechanic		
Switchb'd tender	Starks	1.83	Switchb'd tender	Quail	1.83
1st Fireman	Sanity	2.00	1st Fireman	Yates	2.00
2d "	Smith	1.89	2d "	Bosler	1.83
3d "	Young	1.83	3d "	Maddox	1.83
Coal passer	Darling	1.67	Coal passer	Munns	1.67
Total cost		18.66	Total cost		19.66

OIL AND WASTE.

Day.		Night.		
Cyl. Oil	5 gal.	Cyl. Oil	4 gal.	1.80
Eng. Oil	2 "	Eng. Oil	3 "	.69
Waste	10 lbs.	Waste	10 lbs.	1.40

MAINTENANCE AND REPAIRS

Work done on		Workman's Number.		Amount
Engines	No.	17		
	Rate	175		
	Time	10		1.75
Boilers	No.	16	21	
	Rate	143	15	
	Time	10	8	3.02
Pumps and pipes	No.	18	17	
	Rate	143	12	
	Time	10	10	2.17
Generators	No.			
	Rate			
	Time			
Switchboard	No.	32		
	Rate	13		
	Time	10		1.00
Building repairs	No.	33		
	Rate	15		
	Time	10		1.50
	No.			
	Rate			
	Time			
	No.			
	Rate			
	Time			
Total Cost				10.94

Total Cost of Operation . . . $ 189.23
" " Repairs . . . 10.94
" " Construction . . .
Grand Total . . . 200.17

LINE AND TRACK

(PART 1)

THE LINE

1. The term **line**, when used in connection with an electric railway, covers quite a large field of work. It may apply to the wires used for supplying current to the cars, or to a high-tension transmission line for transmitting the power from a distant power station. It also includes the various devices used for transmitting the current for cars operated by surface-contact or by conduit systems.

OVERHEAD LINE WORK

2. General Features.—When **overhead construction** is spoken of, it is generally understood to refer to the common overhead-trolley system that is used wherever it is permitted, because it is so much cheaper than any of the other systems. Overhead construction includes the setting of the poles, the stringing of the feed-wires and the trolley wire, with its span wires, guard wires, anchor wires, insulating hangers, coupling devices, switches, etc. The feed-wires, or feeders, i. e., the wires communicating directly between the generators at the station and the several points of distribution, are carried overhead or are laid underground if necessary. When the feeders are carried overhead, it is the rule to support them on cross-arms from the same poles that support the span wires and trolley. Sometimes, however, if the feeder followed the line of the track, it would be unnecessarily long; in such a case, its route would lie across country or across town, as the case might be.

3. In Fig. 1, P is the site of the power house, and k–a–$C\,B$–b–e is the trolley wire, which of course has to follow the track. The wire is divided into two sections, a and b, separated by the line circuit-breaker, or section insulator, $C\,B$; the term circuit-breaker used in connection with line work denotes a fitting for putting a break, or insulating joint, in the trolley line. Each section of the wire is fed by its own feeder. Feeder b_1 feeds into section a at a and follows the line of the track up to that point; b_2 feeds the second section at b, but instead of following the track and taking the long path around, as shown by the dotted line, it cuts across, as shown by the full line, thus effecting a great saving in length. It is, as a rule, cheaper in such cases to take the short cut, even if a pole line has to be erected just for the feeder, because great length in a feeder not only means a great outlay in copper, but the additional resistance helps to defeat the purpose of the feeder—that of keeping the voltage up to a practicable value on the line.

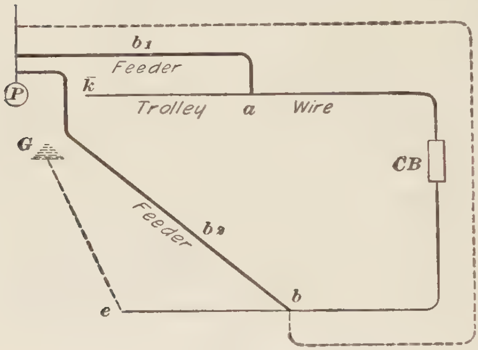


FIG. 1

4. Most overhead-trolley systems use a **rail return,** and it is just as important to provide a good path in the return circuit as in the outgoing lines; in fact, in some cases it is of more importance, because when the rail circuit is poor, current is liable to return on neighboring pipes and thus cause damage by electrolysis, as will be explained later.

Fig. 1 shows that although feeder b_2 allows the current a short path from the power house to the point of distribution b, it does not provide a short path back to the power house. The return current must follow the rail, and it would be very easy under such conditions for a greater drop to take place

in the track return than in the overhead feeder. A ground wire run from some point on the rail in the neighborhood of *b*, or even from the end *e* to the ground bus-bar at the power station, would greatly improve the service.

FEEDERS

5. The distributing system of an electric railway may be generally divided into two parts—the **feeders** and the **working conductor.** The latter usually takes the form of a trolley wire in overhead work, but it may be a third rail or the conductor rail in a conduit system. The feeders are usually in the form of heavy cables run from the station to supply different sections of the working conductor. In small towns and cities or on cross-country roads, feeders are run on poles, because this is the cheapest construction. In large cities, however, they are run underground. City ordinances often prohibit running them overhead on account of their unsightliness and also on account of their being a nuisance and source of danger in case of fires. Underground construction is expensive, but it has its advantages. Electric-railway companies objected very strongly when they were first required to put their feeders underground, but many of them are now strongly in favor of it. Underground wires are not disabled by snow and sleet storms, and on the whole their service is more reliable than that of overhead wires.

Where feeders are run underground, they are usually in the form of lead-covered cables; these are pulled into ducts, and manholes are provided at intervals to allow access to the cables for making repairs and locating faults, as previously explained in connection with the general subject of line construction.

6. General Methods of Feeding.—The simplest method of line construction is to use a single wire, serving both the purpose of trolley wire and feeder; but with a heavy load, the drop of potential at the end of the line, except in special cases, is too great when the trolley wire

alone is used. It is, therefore, necessary to run a heavy cable alongside the trolley wire and tap it into the wire at intervals along the route. Such a plan is shown in Fig. 2, where $m\,n$ is the trolley wire, $a\,b$ the feeder, and f, f

FIG. 2

the taps; the power station is supposed to be at one end of the line at S. It would be much more economical if the power station were in the center, as in Fig. 3, so that it might feed in both directions and thereby halve the distance from the power house to either end of the line.

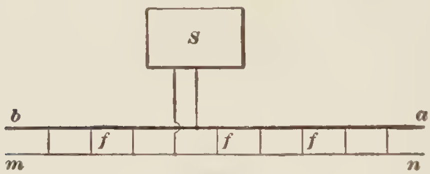


FIG. 3

If the trolley wire is divided into a number of sections c, d, e, f, g, each connected at its center to the feeder $a\,b$, as shown in Fig. 4, the drop in potential at any point would be due only to the feeder and that portion of the trolley line between the point in question and the tap. In case of a fire at any place along the route or in case of a ground on a bridge or in a tunnel, the power could be shut off in that district without disturbing the other parts of the

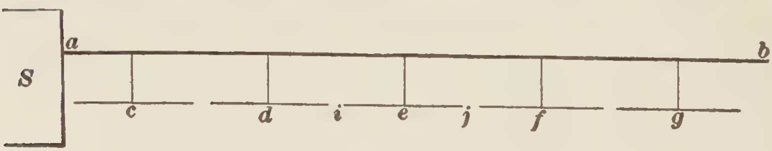


FIG. 4

line. To do this, each tap should be provided with a switch, Fig. 5, mounted on the pole at the point of connection to the feeder. The lower terminal is connected to the trolley, and when the switch is opened the blade can be thrown all

the way down and the door closed. All the exposed parts are then dead and the switch cannot be closed until the door is unlocked. The several sections of the trolley wire are well insulated from one another by line circuit-breakers, or section insulators, which will be described later.

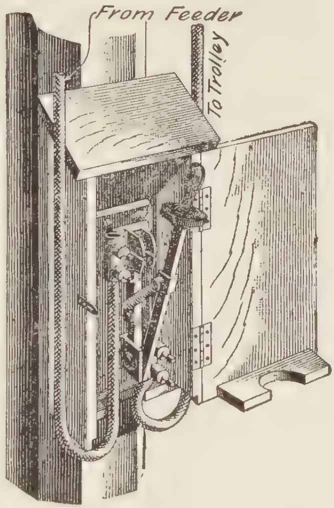


FIG. 5

7. Fig. 6 is a plan of feeder wiring that approaches the condition where the trolley wire is divided into several sections, each of which is provided with its own feeder. But in the case shown in Fig. 6, each feeder supplies several sections of trolley wire by means of extension feeders or mains *a f*, *f b* on the end of the main feeder and an independent tap running to each section of trolley. It is advisable to connect the ends *b i* of the mains by means of a fuse or circuit-breaker, thus tying the different parts of the system together. Then, in case one part is heavily loaded, the feeders and mains supplying the other part can help to supply current. For example, if section *i j* carries a heavy load, current can be supplied by way of feeder *e f* and main *f b*, but if a short circuit or excessive overload occurs on *i j*, the

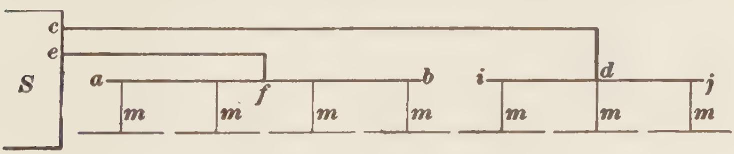


FIG. 6

fuse or circuit-breaker at *b i* will let go before the main circuit-breaker on feeder *e f* in the station, with the final result that current will be cut off from section *i j* but not from the rest of the road. Where several feeders are run out from a

station, it is advisable to tie them together in this manner, because it will help greatly to equalize the voltage, and if circuit-breakers are installed at the junction points and properly adjusted so that they will trip before the circuit-breakers in the station, the power, in case of short circuits or excessive overloads, will be cut off from only that section on which the trouble exists.

Fig. 7 shows the best plan for a feeder service. In this case, each trolley section has a feeder of its own. Of course,

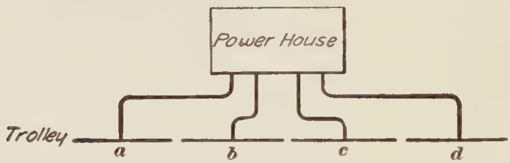


FIG. 7

the feeder is tapped into its section in as many places as may be deemed advisable. Each feeder and its section of trolley wire may be looked on as a single unit, and the idea can be extended to any system, however large. Such a plan not only simplifies calculations, but limits the field for troubles as well. Any trolley section can be cut out by means of its feeder switch.

8. Booster Feeders.—Fig. 8 shows the layout of feeders for an interurban road in Ohio, and illustrates the use of booster feeders for supplying distant sections. The road is 18½ miles long and the power house is situated 6 miles from one end. The two 6-mile sections on either side of the power house are fed directly from the generators, while the two distant sections at the left are fed through boosters. Thus, on section No. *3*, the feeder runs over 10 miles from the power house before it is tapped to the trolley wire, and the feeder for No. *2* section runs for over 6 miles before being tapped. Each section can, therefore, be supplied with different voltages at the power station, thus compensating for the larger drop and maintaining an approximately uniform voltage on all parts of the road. In Fig. 8, the two No. 00 trolley wires are tied together and attached to the feeder,

there being about four trolley-feeder taps to the mile. Current is carried from the rails to the station by four return feeders of 795,000 circular mils each. The trolley feeders are not of the same cross-section throughout, but are reduced in size after they begin to tap into the trolley wire. For example, the feeder for No. *3* section is 715,500 circular mils for $10\frac{1}{4}$ miles from the station and 397,500 circular mils for the remainder of the distance. The road for which this feeding system is designed operates on an average six interurban cars 49 feet 5 inches long over all, equipped with four 75-horsepower motors geared for a maximum speed of 40 miles per hour. The feeders are of aluminum and their cross-section for equal conductivity, if made of copper, would be about 60 per cent. of the cross-sectional areas indicated in Fig. 8.

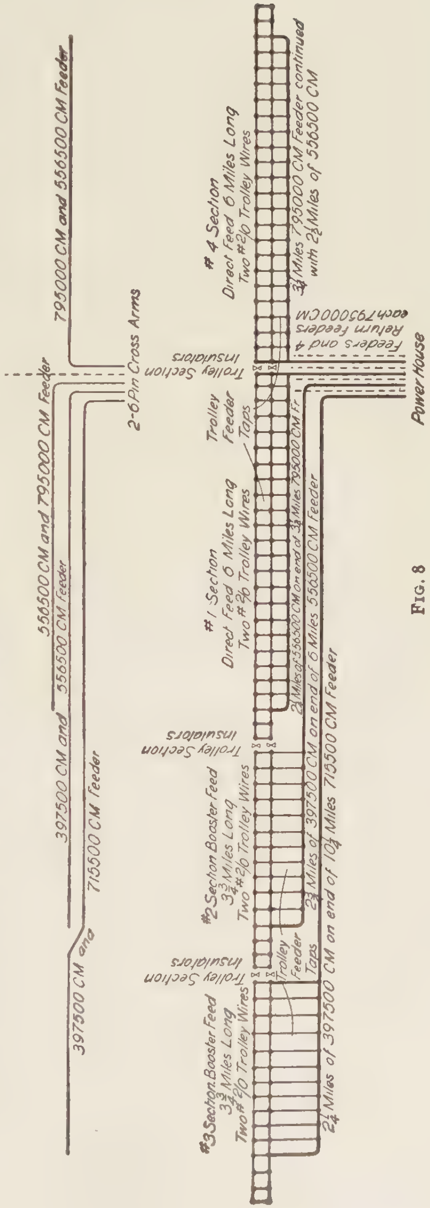


FIG. 8

In selecting the points

to which booster feeders are run, it is frequently advisable to bear in mind the possibility of installing line storage batteries at some future date, and choose locations where sites for storage-battery substations can be obtained without difficulty.

9. Overhead feeders are usually in the form of heavy stranded cables covered with weather-proof braided insulation. If a very large feeder is not required, solid wire may be used or two or more wires may be run in parallel to make up the requisite cross-section. Table I gives the make-up of triple-braided weather-proof railway feeder cables as manufactured by the American Electrical Works.

TABLE I

WEATHER-PROOF FEEDER CABLES

Size Circular Mils	Style of Conductor	Approximate Weight per Mile Pounds
1,000,000	61 wires, .128 each	19,000
950,000	61 wires, .125 each	18,250
900,000	61 wires, .122 each	17,280
850,000	61 wires, .118 each	16,320
800,000	61 wires, .115 each	15,360
750,000	61 wires, .111 each	14,400
700,000	61 wires, .107 each	13,450
650,000	61 wires, .103 each	12,480
600,000	61 wires, .099 each	11,600
550,000	61 wires, .091 each	10,560
500,000	49 wires, .101 each	9,800
450,000	49 wires, .096 each	8,600
400,000	49 wires, .090 each	7,500
350,000	49 wires, .085 each	6,500
300,000	49 wires, .078 each	5,500
250,000	49 wires, .071 each	4,860

Aluminum has been used, in some cases, for railway feeders, but unless the relative prices of copper and aluminum are such that the use of the latter effects a considerable

saving in cost, copper is preferred and is used in the great majority of cases. Since the conductivity of aluminum is about 60 per cent. that of copper, the cross-section of a copper feeder for a given service will be $\frac{6}{10}$ times that of an aluminum feeder for the same service, or the aluminum feeder will have a cross-section of $1\frac{2}{3}$ times that of a copper feeder. For example, if a 300,000-circular-mil copper cable is required for a given service, an aluminum cable for the same service must have a cross-section of $300{,}000 \times 1\frac{2}{3} = 500{,}000$ circular mils.

TROLLEY WIRE

10. Material.—Trolley wire is of hard-drawn copper for all ordinary work. In some cases, especially tough composition wire is used on curves where the wear is excessive. Trolley wire is seldom less than No. 0 B. & S., though on some old lines wire as small as Nos. 1, 2, or even 3 B. & S. was used. Some roads now use No. 000 or 0000, but No. 00 is by far the most popular size, and if the feeding system is laid out properly there is little advantage in using larger trolley wire. It only makes a greater weight to be supported by the span wires and hangers, thus increasing the cost of the line supports.

Hard-drawn copper is used because its tensile strength is greater and its wearing qualities better than soft copper. Its resistance is slightly higher, but this is of little consequence because the trolley is not usually depended on to carry the current for any great distance. Table II gives data on hard-drawn copper.

For trolley wire on curves or other places where there are strain and wear on the wire much greater than on straight stretches of track, **phono-electric** wire is frequently used. This is a special composition or alloy wire made by the Bridgeport Brass Company, and stated to have a tensile strength from 40 to 45 per cent. greater than that of hard-drawn copper; its conductivity is 50 per cent. that of pure copper.

TABLE II

HARD-DRAWN COPPER TROLLEY WIRE

Number B. & S.	Diameter Mils	Area Circular Mils	Weight per 1,000 Feet Pounds	Weight per Mile Pounds	Resistance Ohms per 1,000 Feet	Resistance Ohms per Mile	Breaking Weight Pounds
0000	460	211,600	640.5	3,381.4	.05004	.2642	8,310
000	410	167,805	508.0	2,682.2	.06309	.3331	6,580
00	365	133,079	402.8	2,126.8	.07956	.4201	5,226
0	325	105,535	319.5	1,686.9	.1003	.5297	4,558
1	289	83,694	253.3	1,337.2	.1265	.6679	3,746
2	258	66,373	200.9	1,060.6	.1595	.8423	3,127
3	229	52,634	159.3	841.09	.2011	1.0620	2,480

11. Shape of Trolley Wire.—Trolley wire is nearly always round in cross-section, as this shape answers for most work in towns and cities where the speed is not high. Fig. 9 (*a*) shows the ordinary round wire held by a soldered ear. The ear is tapered down to an edge, so that it will allow the under-running trolley wheel to pass as smoothly as possible. Even if the fins on the ear are thin, there is always more or less of a jump when the wheel passes under the hanger, which causes trouble if the car runs at high speed; the sparking caused by the jump eats away the hanger and leads to breakage in course of time. The jump is even more pronounced if ears that clamp the wire, instead of being soldered, are used.

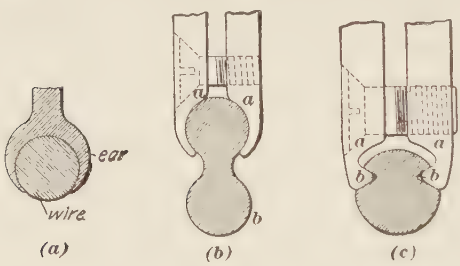


FIG. 9

For cross-country or interurban roads, where high speed is attained, it is very desirable to have the trolley wire so suspended that it will offer a smooth running surface for the

trolley. Fig. 9 (*b*) shows a wire designed to accomplish this. It is the shape of a figure 8 in cross-section and the upper part is gripped by the clamp ears *a*, *a*, the lower part *b* being free from obstruction. The objection to this style of wire is that if it becomes twisted between supports, so that it lies crosswise, the wheel does not run well.

Fig. 9 (*c*) shows a style of wire introduced by the General Electric Company. This wire, also, is supported by clamp ears *a*, *a*, and the surface presented to the trolley wheel is

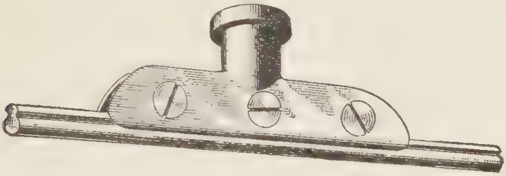


FIG. 10

smooth. The wire is practically circular in cross-section, with the exception of the two grooves *b*, *b* in the side, so that if the wire twists between supports it does not interfere perceptibly with the smooth running of the wheel when high speeds are attained. Fig. 10 shows the method of supporting this wire.

When soldered ears are used, the obstruction offered is so slight that a round wire answers in the great majority of cases. When clamped ears, however, are desired, and when high speeds are developed, these specially shaped trolley wires will be found advantageous.

METHODS OF ARRANGING TROLLEY WIRE

12. There are three styles of support for trolley wires: they may be suspended from brackets on poles at the side of the road; a double track may be provided with center poles carrying the wires on a projecting arm on either side; or the poles may be placed at the sides of the street and the trolley wire supported by span wires stretched across.

13. Span-Wire Construction.—This is the most common method of suspension, and it is preferred for the

following reasons: In the first place, it does not obstruct the center of the roadway like the center-pole construction; in the second place, there are locations where only one side of the road can be used, as on country roads, where passages for two teams must be left outside of the track. Again, where a single track is laid with the prospect of making it a double track if the traffic warrants doing so, the side-pole span-wire construction leaves very little additional work to be done when the time comes for doubling the track. In such a case, it is sometimes the practice to string two trolley wires alongside of each other about 8 or 10 inches apart. As long as the road is single track, the cars use one wire when going one way and the other wire when returning; this saves overhead special work at turnouts and saves copper in the feed-wires. When the time comes for doubling the track,

FIG. 11

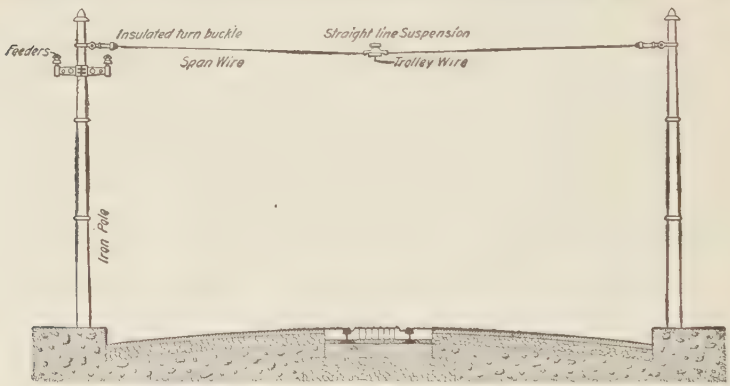


FIG. 12

it is only necessary to slide one wire into place and see to its insulation from the ground. In such straightaway construction, it may be that no feeders are used, in which case the road cannot be divided into sections, but the two wires must be continuous from the power house to the end of the line.

In Fig. 11, $a\,b$ is one trolley wire and $c\,d$ is the other; T is a turnout—a switch where cars can pass each other; the

dotted line *e f* shows the position of the wire *a b* after it has been moved over to the second track. This parallel construction does away with the necessity of any overhead

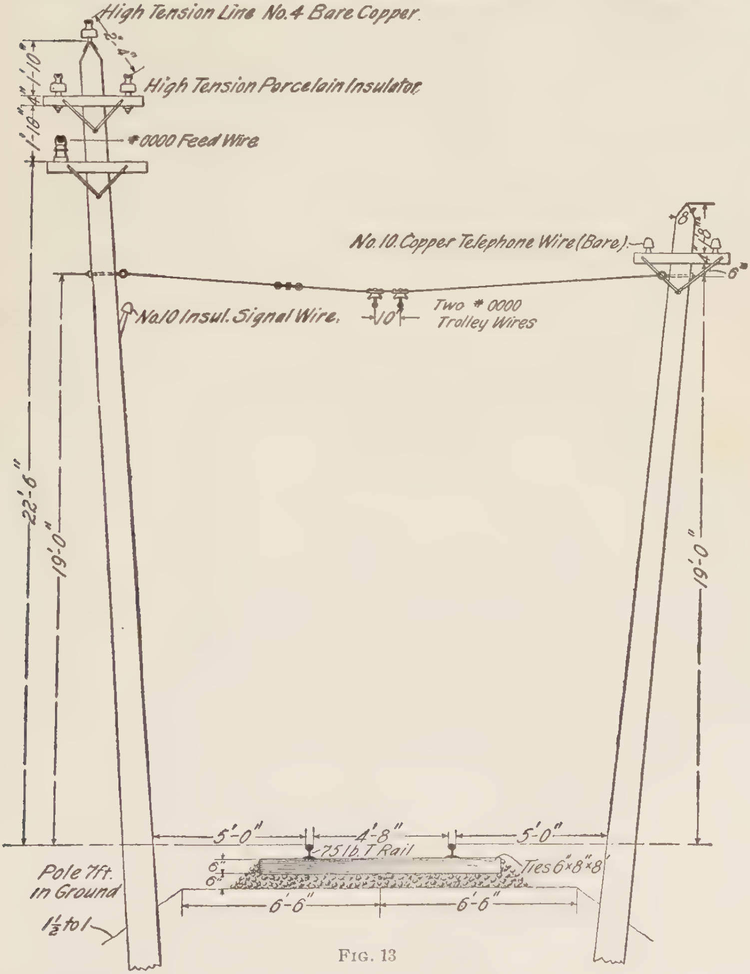


FIG. 13

special work at the turnouts, and if all turnouts are placed on the same side of the track, it leaves one wire straight.

14. Fig. 12 shows a general arrangement for span-wire suspension in cities. In this case iron poles are shown, so

that an insulating turnbuckle is used between the pole and the span wire. The trolley hanger is also insulated, so that there is high insulation between the trolley wire and the ground even though iron poles are used. The feeders are carried on cross-arms bolted to the poles. Where wooden poles are used, the insulated turnbuckles are often omitted. An eyebolt is simply passed through the pole and the span wire is stretched by screwing up a nut.

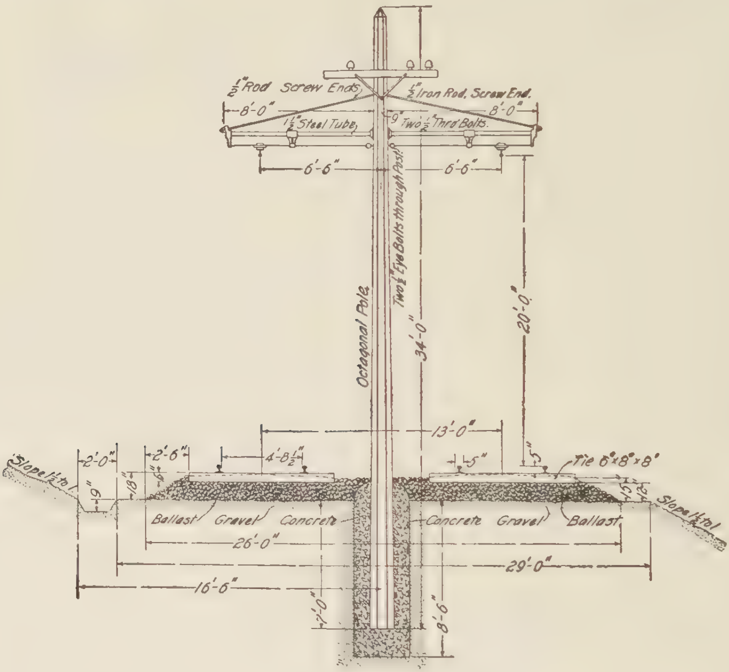


Fig. 14

Fig. 13 shows a span-wire construction for a single-track interurban road where the poles carry a 16,000 volt three-phase transmission line in addition to the direct-current feed-wire. The suspension carries two No. 0000 trolley wires suspended 10 inches apart. The poles are 8 inches in diameter at the top and are set 7 feet in the ground. The span wire is of ⅜-inch twisted steel.

15. Center-pole construction can be used to good advantage on wide streets where poles in the center of the street will not obstruct the traffic. It is also much used for interurban roads operated with an overhead trolley.

Fig. 14 shows a substantial center-pole construction on an interurban road in New York State. The poles are of yellow pine, octagonal in cross-section, and are set in concrete, as shown, in order to give them a firm base. A single No. 000 trolley wire is used over each track and is suspended 20 feet above the rails. The trolley-wire hangers are attached to a small stranded steel cable, thus making the suspension flexible and taking up the blow of the trolley wheel as it passes the supports. The cross-arm carries a 500,000-circular-mil feeder and two No. 10 B. & S. copper telephone wires.

16. Side-Bracket Construction.—When this construction is used, the track is generally on one side of the street; it is used most extensively for cross-country lines where a single track runs along one side of the highway. For this class of work, cheap gas-pipe brackets are generally used; and since the construction calls for only one pole, whereas a span wire requires two, it is less expensive.

Fig. 15 shows a side-bracket construction of good design. The bracket is braced from above and below, a $\frac{1}{2}$-inch tie-rod being used for the upper brace and $1\frac{1}{4}$-inch pipe for the lower. The feeders are carried on the cross-arm and tapped on to the trolley wire, as shown by the connection *a*, *a*. Line lightning arresters are mounted at suitable intervals, five or more to the mile, as shown at *b*, and are connected to ground by No. 00 weather-proof wire *c*. The best way to obtain a ground for these arresters is to attach the ground wire to the rails, as indicated. Two trolley wires of figure 8 cross-section equivalent to No. 00 B. & S. are used; telephone wires are carried on side brackets *d*, *d*.


Local Feeder
Feeder for Distant Section
1/2" Truss Rod 10'-6" Long
a
5"
4"
b
24"
29"
10"
4 1/4" x 3/8" Eye Bolt
1 1/2" Tubing
5/16" Strong
No 00 Trolley Wires
5'-6 1/2"
d
d
Center Line Gauge and Trolley
19'-0"
c
Cedar Pole
19'-0"
20'-0"
30'-0"
4'-8 1/2"
4'-0"
2/0 Tinned Bond
8' Oak Tie
Broken Stone Ballast
5'-6"

FIG. 15

POLES

17. Poles are either of steel or wood. For cross-country or suburban roads wooden poles are generally used, since appearances are not of so much consequence as with city roads; and even in cities, wooden poles are erected when there is no strong objection to them on the ground of unsightliness. For city work tubular wrought-iron or steel poles of the telescope type are very common; these are usually made up of three sizes of pipe welded together. Seamless steel-tube poles are also coming into much favor. Iron or steel poles are invariably set in concrete, for which the following is a suitable composition:

Portland cement	1 part
Clean sharp sand	2 parts
Clean broken stone	3 parts

18. Wooden poles are usually of chestnut, hard pine, cedar, or redwood. The use of redwood poles is confined mostly to a few of the western states. Poles with tops less than 8 inches in diameter should not be used in railway work; they may be suitable for some classes of telephone and telegraph line construction, but they are too light for the heavier work of electric railways. Chestnut poles should, preferably, be second growth and left in their round natural condition. Poles sawed to octagonal shape are usually of hard pine. In general, while sawed poles present a better appearance than round poles in their natural condition, the removal of the outer part of the wood shortens their life. If poles are kept well painted, their life will be prolonged, to say nothing of the improvement in their appearance. The part in the ground should, with the exception of the base, be coated with tar or some other preservative compound. Experience has shown that it is better to leave the bottom uncovered by the tar, because the center of the pole then remains constantly damp and does not rot as quickly. In many cases, poles are treated with creosote in order to prolong their life. Table III gives data relating to untreated poles of best quality American yellow pine or cedar.

TABLE III

APPROXIMATE SIZES, WEIGHTS, ETC. OF WOODEN POLES

Length Feet	Diameter Top Inches	Diameter Bottom Inches	Volume Cubic Feet	Shape of Section	Weight Pounds	Allowable Side Strain for 7-Inch Deflection
28	8	10	12.5	Circular	600 to 700	725
28	8	10	13.2	Octagonal	650 to 800	725
30	8	10	13.4	Circular	670 to 820	700
30	8	10	14.2	Octagonal	700 to 840	700
30	9	12	19.1	Octagonal	900 to 1,140	850

19. Setting Wooden Poles.—Wooden poles are not, as a rule, set with concrete, although there is no good reason why they should not be. When the side-pole span-wire construction is used, they should have their earth bearing increased by the proper disposal of several large stones. A couple of stones should be jammed into the hole alongside of the pole on the side away from the track and a couple more near the mouth of the hole on the side next the track. This will do a great deal toward preventing the span of wire from pulling the tops of the poles together. A piece of timber may be substituted for the stones on the track side, in which case it should be about 3 feet long and 8 square inches in cross-section. After the pole has been placed in position, it should be solidly tamped around to make a firm bed. The tamping should be done while the pole is free; if done while there is tension on the span wire, the effect will be just the opposite to that desired. On straight stretches of track, using side-bracket construction, the poles should be given a rake backwards from the track, the top of the pole not being more than 2 or 3 inches out of plumb. Where side poles are used, with span wires, the rake should be considerably greater because of the tendency of the span wire to pull the tops together (see Fig. 13). In soft ground, the rake should be from 8 to 12 inches, depending on the character of the ground and the kind of pole foundation; the more yielding

the soil the greater should be the rake. In setting poles having a rake, it is advisable to use a spirit level or plumb-bob; by doing this they will all be on a uniform slant, whereas if the eye alone is depended on, the pole line may be very uneven. The poles are usually spaced from 100 to 125 feet apart. In cities 100 feet, or about 53 to the mile, is a common average; while in other places, where a lighter construction is sufficient, they may be placed 125 feet apart, or about 42 to the mile.

20. Tubular Steel Poles.—Fig. 16 shows a tubular steel pole adapted to the various types of construction, (*a*) being for the side bracket, (*b*) for the center pole, (*c*) for the span wire. The method of attaching the span wire to the pole in (*c*) is shown in the small detail sketch. A

TABLE IV

APPROXIMATE WEIGHTS OF IRON POLES

Style of Pipe	Diameter of Sections			Length Feet	Weight Pounds
	Bottom Inches	Middle Inches	Top Inches		
Standard	5	4	3	27	350
Extra heavy . . .	5	4	3	27	500
Standard	6	5	4	28	475
Extra heavy . . .	6	5	4	28	700
Standard	7	6	5	30	600
Extra heavy . . .	7	6	5	30	1,000
Standard	8	7	6	30	825
Extra heavy . . .	8	7	6	30	1,300

clamp is fastened around the pole and to it is attached a turnbuckle that allows the tension on the span wire to be adjusted. Usually this turnbuckle is insulated in order to provide insulation between the trolley wire and ground in addition to that afforded by the trolley-wire hanger. Feed-wires are carried on an iron cross-arm bolted to the pole,

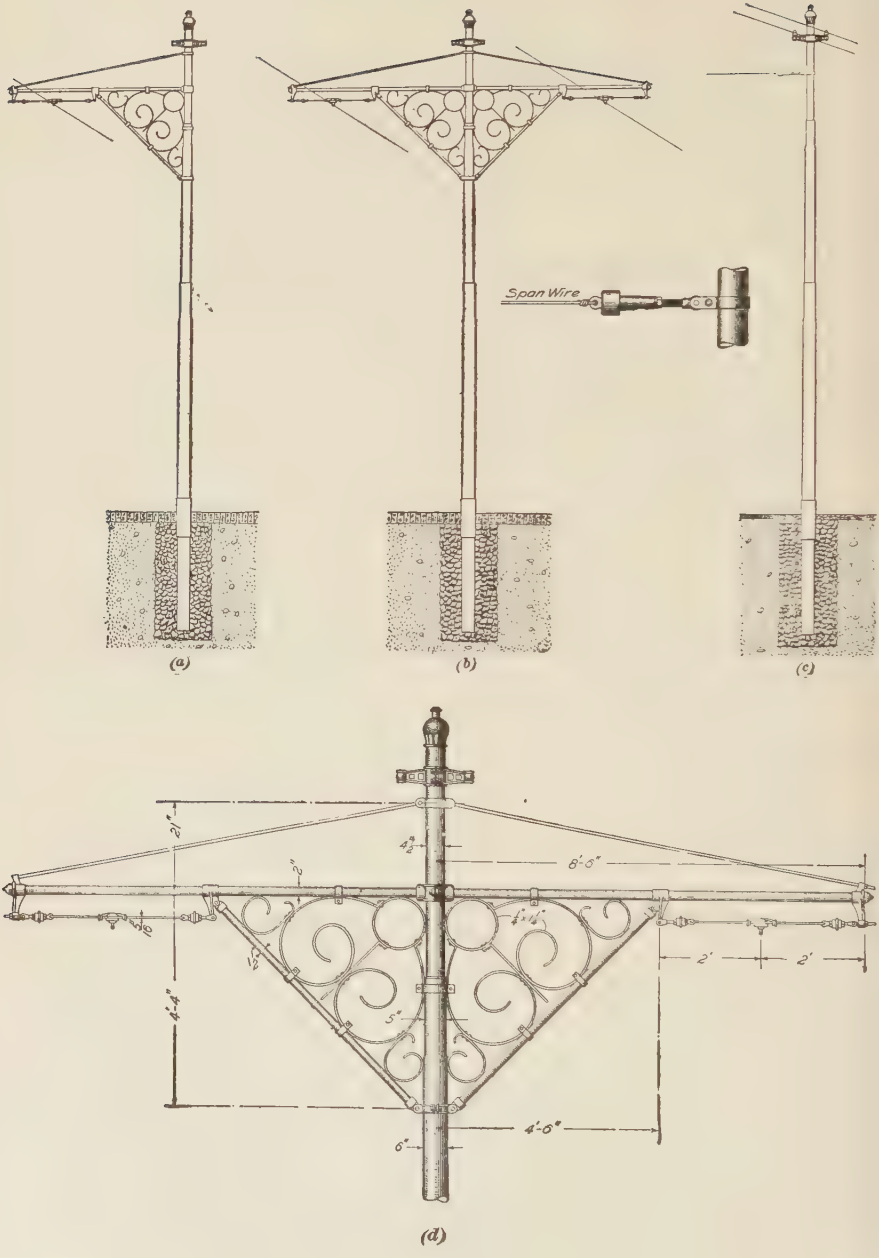


FIG. 16

as in (*c*). An enlarged view of the center-pole top is shown in (*d*). The trolley-wire hanger is not fastened rigidly to the horizontal cross-arm but is flexibly supported from a short span wire stretched between brackets; the span wire is usually made of stranded steel cable about $\frac{5}{16}$ inch in diameter. Table IV gives the approximate weight of iron poles.

Steel poles are sometimes made in other than the telescope tubular form. Poles made of pressed steel parts riveted together have been used; also latticework poles built up of structural steel. In the majority of cases, however, the telescope type of pole is the one generally adopted.

LINE FITTINGS AND LINE ERECTION

TROLLEY WIRE AND FEEDERS

21. The general arrangement of wiring for a double track is shown in Fig. 17. The poles *p* are placed not more than 125 feet apart measured along the road, and between opposite poles are stretched the span wires *s*. At intervals of about 500 feet and at the approach to all curves, anchor wires *a* are put up, being secured by special hangers, as at *h*. These take up the strain on the trolley wire in the

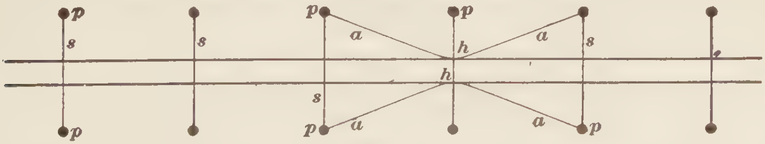


FIG. 17

direction of its length, for it must be borne in mind that the trolley wire is put up under considerable tension, so that should it break it would draw apart in both directions if there were no anchor wires to hold it in position. The two general methods of stringing the trolley wire depend on whether it is put up dead or alive; i. e., whether the current is off or on. In the first case, the wire is run off the reel

under the span wires and is then raised and tied temporarily to them; the tension is put on afterwards and the wire fastened to the insulators.

If the wire is put up alive, the reel is put on a flat car that is moved by a trolley car. As fast as the wire is paid off, it is fastened to the insulators, once for all, by a line crew that follows close behind. It may be necessary to go over the

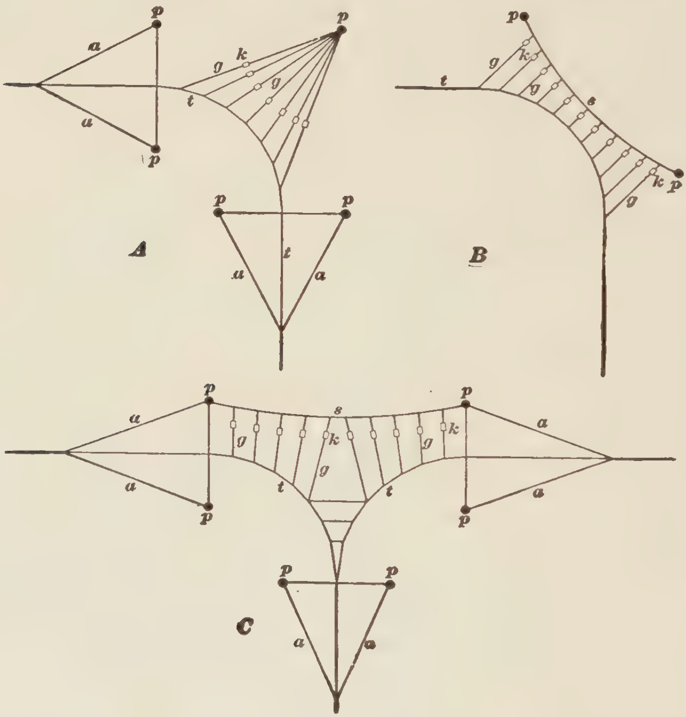


FIG. 18

road afterwards and make a final adjustment, especially at curves and crossings.

22. Erection at Curves.—The method of securing the trolley wire at curves is shown in Fig. 18, where A represents the arrangement of guy wires g attached to the trolley wire t when a single pole is used. Strain insulators are

usually inserted, as shown at k, and the trolley wire, at the beginning of the tangent or straight portion, is held by anchor wires a. A flexible method of suspension is shown in diagram B, where a heavy span wire s holds up the guy wires; this form of construction tends to equalize the strains on the span wires, and is generally adopted in place of A, which is the older method. A double curve is shown at C, the different wires and poles being designated by the same letters as in the preceding layouts.

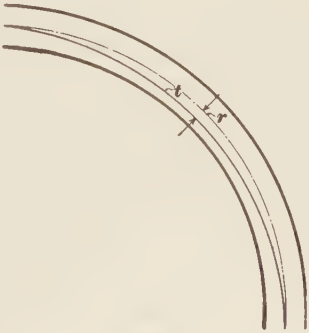


FIG. 19

23. Offset in Trolley Wire. In going around a curve, the trolley wire does not follow the center line between the rails as it would do if the trolley wheel were applied to the wire at a point immediately over the center of the car, but it is shifted over toward the inside rail by a distance that depends on the radius of the curve. This departure from the center line of the track is shown in Fig. 19, where the curve r is the center line of the rails and t the path of the trolley wire. The amount of offset measured at the middle of a 90° curve at the point indicated by the arrows in the figure should be about as follows:

Radius of Curve	Offset
40 feet	16 inches
50 feet	13 inches
60 feet	12 inches
80 feet	8 inches
100 feet	6 inches
120 feet	5 inches
150 feet	4 inches
200 feet	3 inches

The object of the offset is to allow the trolley wheel to lie more closely to the wire; it would not do this so well if the wire followed the center line of the track, as the wheel

would lie diagonally across the wire and cause a large amount of wear on curves.

24. Guard Wires.—In some places, guard wires are located above the trolley wires, as shown in Fig. 20. They are placed about 18 inches above and to one side of the trolley wire, their object being to prevent telephone or other wires from falling across the trolley wire. Guard wires are now very little used, as they are of doubtful advantage and

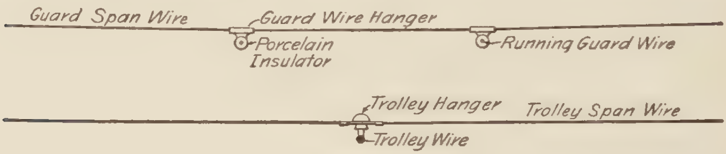


FIG. 20

are themselves apt to break and come in contact with the trolley wire. They are, however, useful in some special places, as, for example, at railway crossings. They have usually been made of No. 6 or 8 B. W. G. bare galvanized-iron wire, but it is now considered better to use weatherproof insulated iron wire, as the insulation adds much to the effectiveness of the guard.

25. Tension on Trolley Wire.—In putting up trolley wire, judgment must be used regarding the tension put on it. Thus, wire strung in hot weather must be allowed more sag than that put up in cold weather, otherwise the contraction will put severe strains not only on the trolley wire itself, but on the whole overhead construction. A range of 80° F. between summer and winter temperatures is not at all unusual, and this corresponds to a variation of nearly 4 feet per mile in the length of the trolley wire. For a 125-foot span of No. 0 wire, put up with a tension of 2,000 pounds, the sag at the center of the span will be, according to Mr. E. A. Merrill, 3.8 inches; for a tension of 1,500 pounds, 5 inches; for 750 pounds, 9.5 inches; for 500 pounds, 15 inches. Dawson recommends as a safe allowance for localities where the temperature does not fall below −20° F., a sag equal to three-fourths of 1 per cent. of

the span when the wire is strung at the ordinary temperature of 60° to 65° F. Thus, for a 125-foot span, a sag of about $11\frac{1}{4}$ inches would be allowed, and in the warmest weather the sag would not exceed 15 inches.

26. Span Wire.—Span wire is usually made of galvanized iron or steel, and in the best construction, stranded wire is always used. A common size is $\frac{5}{16}$ inch in diameter, made of seven strands, No. 12 B. W. G. Where a heavier construction is desired, $\frac{3}{8}$-inch stranded wire, made of seven strands, No. 11 B. W. G., is used. Solid span wire is not desirable, but in case it is used, the size should not be smaller than No. 1 B. & S. for No. 0 trolley wire. Span wires should be placed so that the trolley wire will be from 19 to 20 feet above the top of the rail. Of course, there are places where this rule cannot be adhered to, for at steam railroad crossings the wire must be higher than 19 feet, and under elevated structures it must be much lower.

27. Insulators.—The hanger supporting the trolley wire is always constructed so as to provide thorough insulation, except in cases where it is used to connect the trolley wire to a feeder. With wooden poles, the hanger provides sufficient insulation between the trolley wire and ground, so that it is not necessary to insulate the span wire from the

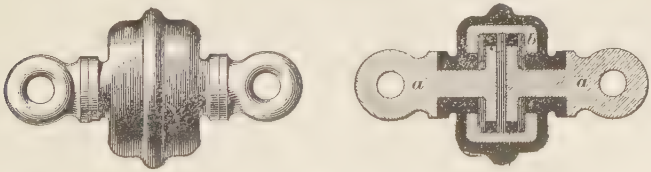


FIG. 21

poles. With iron poles, insulators are generally used in the span wire as an additional precaution. Fig. 21 shows an ordinary strain insulator much used whenever a span wire or pull-off is to be insulated from the pole. The span wires are attached to a, a, and the pull is taken up against piece b, which is separated from a, a by insulating material. The whole insulator, with the exception of the two eyes, is

covered with molded insulation. Fig. 22 shows two styles of insulated turnbuckle for span-wire construction with iron poles.

FIG. 22

28. Trolley-Wire Suspensions.—The hangers for suspending the trolley wire are made in a great variety of designs, but in general they consist of three parts, namely,

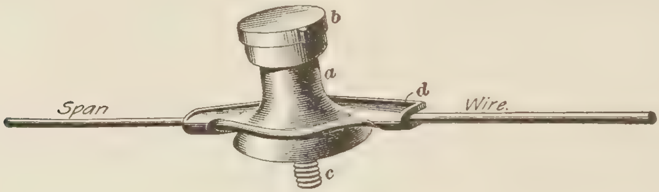


FIG. 23

a casting or body that is held by the span wire or bracket, an ear that grips or is soldered to the trolley wire, and an insulating material that separates the ear from the casting.

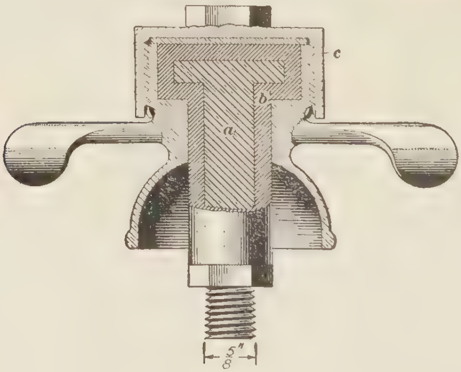
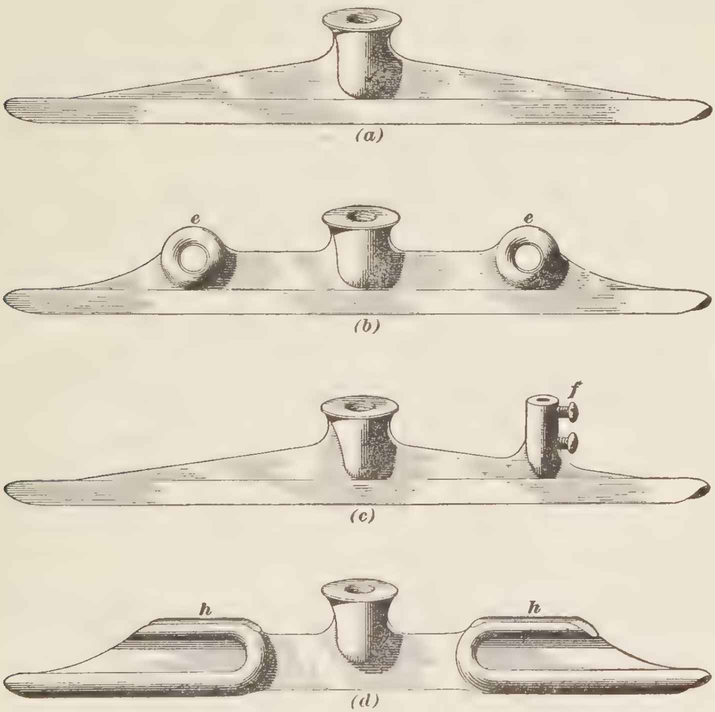


FIG. 24

Fig. 23 shows a common form of suspension with the ear removed; *a* is the main casting provided with the grooved extensions *d*. The span wire passes through *d* and around *a*, thus holding the hanger in place; by using a special tool, hangers are easily sprung into place on the span wire. Bolt *c* is bedded in molded insulating material and the casting is covered by a metal cap *b*. The ear to which the trolley wire is fastened screws on *c*. Fig. 24

is a sectional view of a hanger very similar to that in Fig. 23. The bolt *a*, with its molded insulation *b*, is held firmly in place by the screw cap *c*, but can be easily removed by unscrewing the cap.

The metal castings for overhead fittings are made either of malleable iron or brass. The ears, when soldered, are



(a)

(b)

(c)

(d)

FIG. 25

made of brass; those designed to clamp on the wire are usually made of malleable iron.

Fig. 25 shows four styles of ears intended for soldering to the trolley wire. They are provided with a groove on the under side, in which the wire lies. The ear shown at (*a*) is known as a **plain ear**; it is used for ordinary straight-ahead work. (*b*) shows a **strain ear**, so called because it is provided with lugs *e*, *e*, to which the wires *a*, *a*, Fig. 17, are

attached. (*c*) is a **feeder ear**; it is provided with a lug *f*, to which the tap from the feeder attaches. (*d*) is a **splicing ear,** used where the trolley wire comes to an end at a hanger. This ear serves the double purpose of holding the wire and acting as a splice. The ends of the trolley wire are passed up through two openings *h*, *h* and bent back over. Feeder ears and splicing ears are used comparatively little.

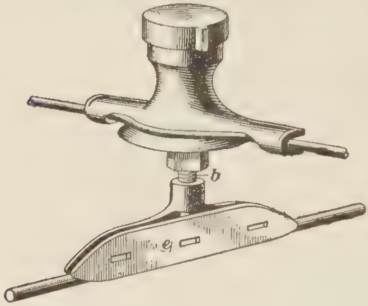


FIG. 26

Fig. 26 shows a suspension provided with an automatic ear. This ear is made in two parts that are hinged together. When *b* is screwed up, the ear *e* clamps the wire, thus holding it firmly without the use of solder. Automatic ears make more or less of a projection, and hence tend to make the trolley wheel jump more than soldered ears. They are, however, easy to put up and are especially useful for temporary work or in places where the location of the hangers may have to be changed.

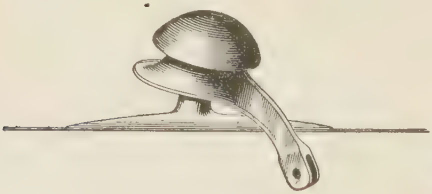


FIG. 27

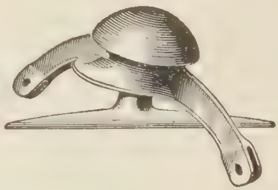


FIG. 28

29. In rounding a curve, the trolley wire is at first stretched in temporary wire slings and anchored, after which the hangers or pull-over clamps are attached. For ordinary curves, suspensions such as shown in Figs. 27 and 28 may be used. Fig. 27 shows a single-curve suspension used with single-track work; Fig. 28 is a double-curve suspension used

where there are two trolley wires and where a span wire or pull-off wire must be attached to each side of the hanger.

For suspending trolley wires and making repairs on the same, a "tower wagon" is used; this consists of a platform

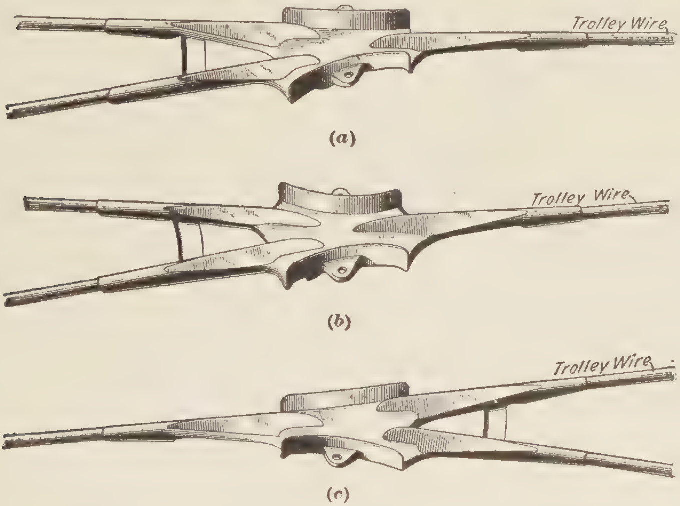


Fig. 29

supported on a wagon at a convenient height for ready access to the wires. This platform is generally so arranged as to project beyond the wagon, so that the latter may stand clear of the tracks while repairs are in progress and not

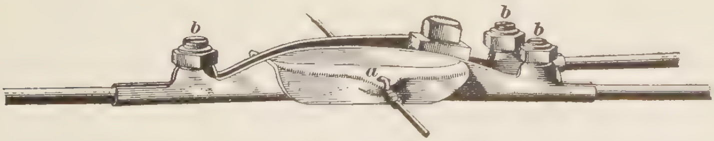


Fig. 30

interfere with regular traffic. When not in use, the platform may be lowered to the wagon by means of a winch.

30. Frogs.—At the point where one line branches from another, overhead switches, or **frogs**, are used to guide the trolley wheel from one wire to the other. Fig. 29 (*a*) shows

the under side of a simple two-way **V** frog of a type that is largely used; (*b*) is a right-hand frog and (*c*) a left-hand frog. In these frogs the trolley wire is soldered into the ears. Fig. 30 shows a **V** frog in its natural position. In this case, the trolley wire is held by clamps *b*, *b*, *b* and no solder is necessary. The span wire is attached to the ears ***a***.

31. It is necessary that frogs be placed correctly with relation to the track, and mechanical fastenings for the wires are therefore desirable, because they allow the frog to be adjusted to the position giving the best results. The satisfaction that any frog will give depends a great deal on how it is put up. If put up level, the trolley is very likely to follow the same direction as the car, but if allowed to sag down on one side, it will be a never-ceasing source of trouble, due to its throwing the trolley wheel off the wire. The position for the frog may be found by the method

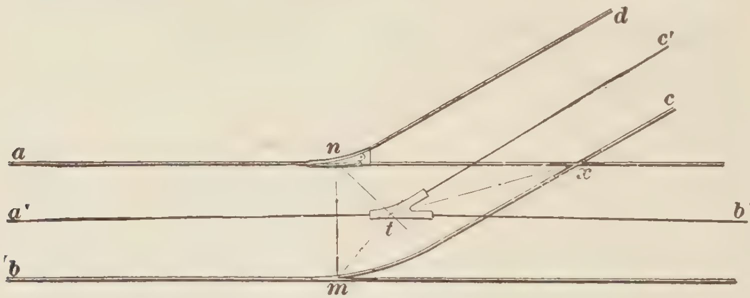
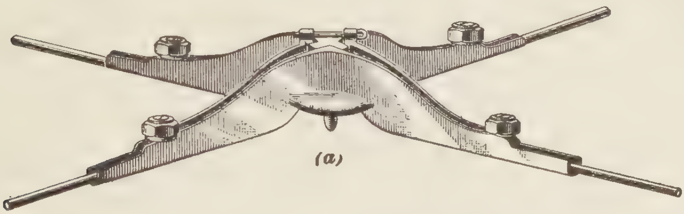


FIG. 31

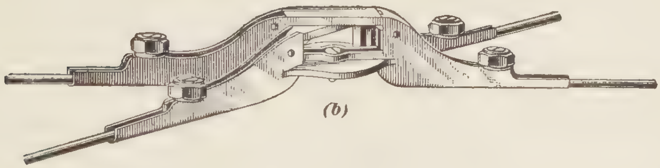
shown in Fig. 31, where *a* and *b* are the main-line tracks, *c* and *d* the branch-line tracks, $a'\,b'$ the main trolley wire, and $t\,c'$ the branch trolley wire. The center of the triangle $n\,x\,m$ will be at a point t where the lines bisecting each angle meet; and this determines the position of the frog. It will be a little removed from the center lines of the tracks. In practice it is often found necessary to shift a frog after it has been put up in order to make the trolley wheels run over it without jumping off. Lateral adjustment can be obtained by means of the turnbuckles attached to the span

wires. When a frog is first connected, the trolley wire should be left long and the end coiled up on top of the frog so that the latter can be shifted forwards or backwards in case such adjustment is afterwards found necessary.

32. Cross-Overs.—At the point of intersection of two trolley lines, a device called a **cross-over** is used. Fig. 32



(a)



(b)

Fig. 32

shows two common forms of cross-overs; (*a*) is used where the two lines cross at right angles, (*b*) where they cross at an acute angle. Where the intersecting trolley wires belong to different companies, it is necessary to insulate the wires

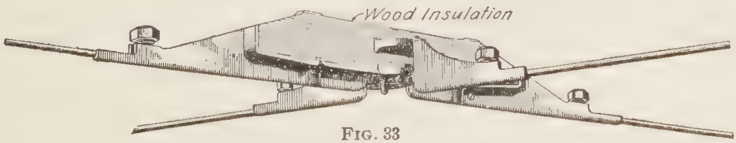


Fig. 33

from each other. In such a case, a special insulating trolley crossing, Fig. 33, must be used.

33. Section Insulators.—Section insulators are placed at the junction of two divisions that are fed by separate feeders from the power house, and are commonly known as

line circuit-breakers or simply **line breakers.** The direct line of the trolley wire is unbroken, allowing the trolley wheel to run smoothly across the insulating material (usually hardwood) that separates the two castings to which the sections of trolley wire are attached. Figs. 34 and 35 show two satisfactory types of section insulators, the insulating material in both cases being hardwood.

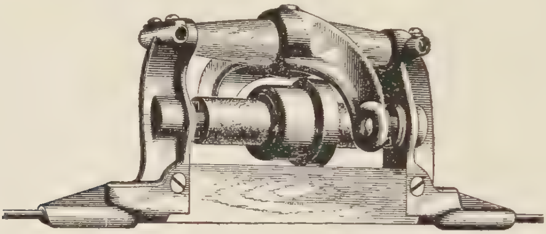


Fig. 34

The main requirements for line devices of any kind are simplicity, durability, and strength. There is no place on the road where appliances are subjected to as violent knocks as they are on the line when struck by a pole that flies off under a tension of 20 or 25 pounds with the car going 20 or 30 miles an hour. Where the device has an insulator, this

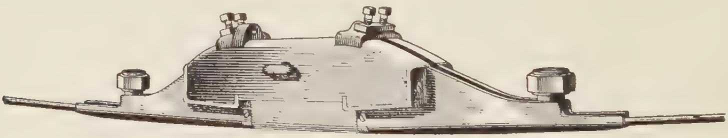


Fig. 35

must be effective; for while the leakage current over one may be small, that for hundreds of them in parallel may amount to considerable. Every line should be subjected to a constant and careful inspection, and as soon as a fault begins to assert itself, it should be remedied at once.

34. Feeder Splicing.—The feeders, if they are not in the form of large cables, are usually joined by using the

ordinary Western Union joint, Fig. 36, or by a long twisted joint, as in Fig. 37. In the latter case the insulation is removed for about 2 feet from the ends, and the wires twisted together while under tension and then soldered. This makes a good joint and it is much neater and less bulky than the Western Union when used with large solid wires, such as No. 000 or No. 0000.

FIG. 36

A solution of resin in alcohol makes a good flux for soldering such joints, as it does not corrode the wire.

Large feeder cables may be joined either by weaving the strands together and soldering or else by using a copper sleeve and thoroughly soldering the ends into it. Another effective method of joining cables is to slip a heavy copper

FIG. 37

sleeve over the joint and then subject this sleeve to very heavy pressure by means of a special portable hydraulic press. All overhead wires after being spliced should be thoroughly taped, so as to provide an insulation at least equal to the covering on the wire.

35. Splicing Trolley Wires.—When a trolley wire is spliced, the joint has to be mechanically strong, because there is considerable strain on the wire; also, the joint must offer as little obstruction as possible to the passage of the trolley wheel. The most common method of splicing trolley wire is by means of a tinned tapered brass sleeve, Fig. 38. The wires go in at each end of the connector and are bent up through the openings *a*, *a*. The remaining space is then poured full of melted solder and the ends of the wire trimmed off. This connector will give excellent service if care is taken to see that it is made of heavy enough material and is a good fit for the wire. (*b*) shows dimensions for a satisfactory connector for No. 00 wire.

The splicing ear shown in Fig. 25 (*d*) represents another device for splicing trolley wire. The general idea is the same as that used in the tubular trolley connector, except that it must be used at a point of support, as indicated by the lug for attaching to the hanger. The ends of the wire to be

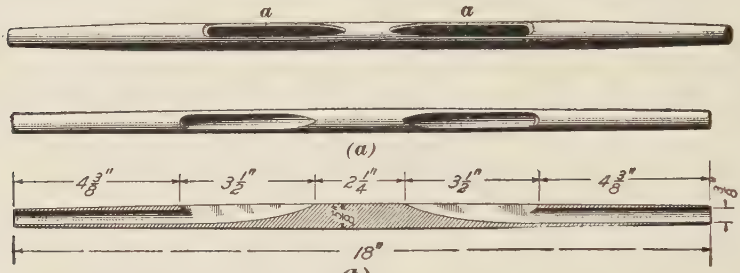


Fig. 38

spliced go into the ear at the ends, pass up through the holes *h*, *h*, and are turned back and trimmed off. The fins on the lower edge of the ear are clinched and the whole is then sweated with solder and cleaned off. Splicing ears do not always call for the use of solder; in some of them the wire is held by means of screw clamps, but they all have the disadvantage that a splice cannot be made except where there is a hanger, whereas with a sleeve connector, a splice can be made anywhere on the line.

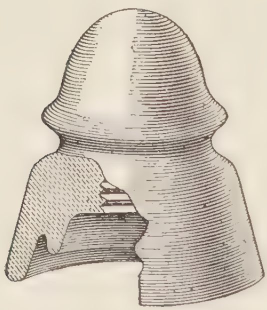


Fig. 39

36. Feeder Insulators.—Heavy glass insulators may be used for supporting feeders of ordinary size. In the case of large feeders, however, the strain is very great and glass insulators are liable to crack. This is especially so at curves, where the strain on the insulator may be very heavy.

Where the heavy feeder cable subjects the pole insulator to a side strain, as at corners and curves, insulators of

composition material, such as molded mica, are used, because this material is tougher than glass and does not crack under the strain. Fig. 39 shows one of these insulators having a groove large enough to take a cable up to 500,000 circular mils cross-section. Fig. 40 shows another style where the top is made of bronze and the lower part of molded insulation. The feeder rests in the groove and is held in place by the screw cap *a*. Fig. 41 shows still another style, in which the cable also rests in a groove on top, but is held in position by means of a tie-wire.

FIG. 40

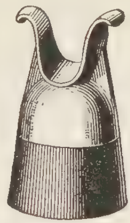


FIG. 41

37. Connecting Feeders to Trolley Wire.—Fig. 42 shows the most common method of tapping the feeder to the trolley wire. A piece of solid weather-proof feed-wire (No. 00 to 0000) is tapped on to the feeder and is fastened to the strain insulator *a* by passing the end of the wire through the eye of the insulator and giving it a few turns around itself. The other end of the feed-wire is attached to one end of strain insulator *b*, which is placed at some distance to the left of the trolley hanger so that it will not be struck in case the trolley wheel flies off the wire. For the balance

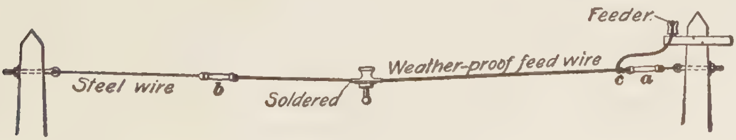


FIG. 42

of the span from *b*, ordinary steel span wire is used, though in some cases the copper wire is run clear across and strain insulator *b* placed near the pole in the same position as *a*. The weather-proof insulation is removed from the feed-wire at the point where the trolley-wire hanger is attached, the hanger having a solid brass bell, without the usual insulation, soldered to the span wire.

38. Line Lightning Arresters.—The overhead distributing system of an electric railway should be liberally supplied with lightning arresters. There should be at least five to the mile and a good ground connection should be provided by connecting to the rail. The arresters used for this work are practically the same as those for indoor location in power stations, except that they are enclosed in weather-proof cases.

THE TRACK

39. The **track** on which electric cars are to run must be substantially constructed. Each car carries its own motors and the track is subjected to much greater wear and tear than if the cars were propelled by some outside source of power, as, for example, on a cable road. The rails are subjected to the grinding action of the wheels whenever slippage occurs and the weight of the motors on the trucks is so great that unevenness in the track causes severe pounding. When electric railroads were first installed, the track construction was altogether too light and the whole tendency has been toward heavier construction, until at present the trackwork on the best electric railways is fully as substantial as that on trunk-line steam roads. On most electric railways, the track is used for one side of the circuit and the rail joints must therefore be of good conductivity. Special precautions must be taken to see that the joints are so made that they will not deteriorate rapidly; they should also provide a conductivity at least as good as a length of rail equal to the length of the joint, but on many roads the conductivity is not up to this standard. Rails for electric roads, as now built, seldom weigh less than 60 pounds per yard, and in most cases weigh more. Many interurban roads use rails weighing 80 or 90 pounds per yard, and for city tracks, where high rails must often be used on account of paving, the weight will run over 100 pounds per yard.

The kind of roadbed and rail to be used depends on where the road is located. If the soil has a very poor bottom, the

subwork must be more substantial than where the soil is firm or where there is rock. The construction also depends a great deal on the traffic, and in many cases on city ordinances that call for a certain class of rail.

RAILS

40. Composition of Track Rails.—Rails are always of mild steel; i. e., steel containing a low percentage of carbon, together with manganese, silicon, and very small percentages of sulphur and phosphorus. The percentages of carbon and manganese have a marked effect on the hardness of the rail; if small, the rail will be soft and its wearing qualities poor; if high, the rail will be brittle and its electrical conductivity will be low. Table V shows the limiting percentages of carbon, phosphorus, silicon, and manganese as specified for track rails for a number of prominent street-railway systems in the United States. These will give an idea as to what is considered a desirable composition for rails; it will be noted that the percentages of the different substances do not differ greatly.

41. Cross-Section and Weight of Rails.—Rails are always designated by the number of pounds per yard that they weigh. Thus, a rail weighing 60 pounds per yard is known as a 60-pound rail; one weighing 80 pounds per yard, as an 80-pound rail; and so on. The weight in pounds per yard divided by 10 gives the cross-sectional area, in square inches, approximately. For example, an 80-pound rail would have a cross-section of $\frac{80}{10} = 8$ square inches. We may write

$$A = \frac{W_y}{10} \qquad (1)$$

where A = area of rail section, in square inches;
W_y = weight of rail, in pounds, per yard.

Rule I.—*To find the area of cross-section of a rail, divide the weight, in pounds, per yard by 10.*

TABLE V
RAIL COMPOSITION

Road	Carbon Per Cent.	Phosphorus Per Cent.	Silicon Per Cent.	Manganese Per Cent.	Sulphur Per Cent.	Remarks
Boston	.50 to .60	Not over .08	.10 to .15	.80 to 1.00	Not over .08	Rails with carbon below .50 per cent. or above .62 per cent. will be rejected
Buffalo	.43 to .53	Not over .10	Not to exceed .20	.80 to 1.10		
Denver	.46 to .56	.10 or less	.10 or over			
Philadelphia .	.45 to .55	Not over .10	.20	.80 to 1.00		
	.37 to .45	Not over .10	.07 to .15	.70 to 1.10	Not over .05	Illinois Steel Co. standard specification for rails under 70 lb.
	.45 to .55	Not over .10	.10 to .20	.80 to 1.00	Not over .05	Same for rails over 70 lb. per yard

To find the weight of rails required per mile of single track, the following simple formula may be used:

$$W_t = 1.76\ W_y \qquad (2)$$

where W_t = weight of rails, in tons, for 1 mile of single track;

W_y = weight of rail, in pounds, per yard.

Rule II.—*The number of tons weight of rail required for 1 mile of single track is equal to 1.76 times the weight of the rail, in pounds, per yard.*

42. Resistance of Track Rails.—Since, in most electric railways, the track is used as one side of the circuit, it is important to know the electrical resistance of steel. The resistance of mild steel varies greatly with its composition, the harder the steel, the higher is the resistance. Track rails are selected for their wearing qualities; hence, a certain degree of hardness is essential; but where a rail is used simply as a working conductor, as in third-rail systems, it can often be made of softer steel, because the only wear to which it is subjected is that of the collecting shoes.

Extended tests made by Mr. J. A. Capp on specimens of rails obtained from different sources show specific electrical resistances varying from 6.4 to 13.2 times that of copper. A fine grade of Swedish wrought iron showed a resistance of about 6 times that of copper. It has been customary to assume, in making calculations regarding track resistance, that steel ordinarily used in track rails has a specific resistance of 7 times that of copper. However, tests show that in most cases the specific resistance is much higher than this, and to be on the safe side, 10 would be more nearly in accordance with the facts and will be so taken here.

43. Steel for Conductor Rails.—In most cases where roads have been operated by a third rail or from special conductor rails, as in slot systems, the rails have been rolled from material the same as used for the track. Rails rolled of special steel to secure higher conductivity would

cost too much in the majority of cases. Mr. Capp's tests show that by properly limiting the impurities in the steel there is no difficulty in securing a composition that can be made without greatly increasing the cost and that will have a resistance not over 8 times that of copper. The element having the greatest effect on the resistance is manganese, and if the percentage of this is kept down, the other impurities can be present in a considerable amount without causing a very high resistance. Chemically pure iron has a resistance approximately 4.5 times that of copper, and comparatively small percentages of impurities increase the resistance in a marked degree. Pure iron, even if it could be obtained at reasonable cost, would not be suitable for conductor rails because it would not be hard enough to stand the wear of the collecting shoes. At the same time, if a conductor rail is made with percentages of carbon and manganese lower than ordinarily used, the conductivity can be improved. Mr. Capp recommends the following composition as giving a resistance not exceeding 8 times that of copper: Carbon not to exceed .15 per cent.; manganese not to exceed .30 per cent.; phosphorus not to exceed .06 per cent.; and silicon not to exceed .05 per cent. On some large systems, for example, on the New York subway, where the length of conductor rail is sufficient to warrant the preparation of special steel, it has been used; but for ordinary roads, standard rails have in many cases been installed.

44. Formulas for Track Resistance.—A copper bar of 1 square inch cross-section has an area of 1,273,236 circular mils. The resistance of 1 mil-foot of commercial copper may be taken as 10.8 ohms; hence, the resistance of a bar of copper 1 square inch cross-section and 1 foot long would be $\frac{10.8}{1,273,236}$, and a bar 1 yard long would have a resistance of $\frac{10.8 \times 3}{1,273,236}$ ohms. If W_y is the weight of a rail, in pounds per yard, its cross-sectional area, in square inches, is $\frac{W_y}{10}$;

and if we assume that the resistance of ordinary rail steel is 10 times that of copper, a rail having a cross-section of $\frac{W_y}{10}$ square inches will be equivalent to a copper bar of $\frac{W_y}{100}$ square inches cross-section. Hence, if the resistance of 1 yard of copper bar of 1 square inch cross-section is $\frac{10.8 \times 3}{1,273,236}$ ohms, a yard of rail of weight W_y will have a resistance of $\frac{10.8 \times 3}{1,273,236 \times \frac{W_y}{100}} = \frac{.00254}{W_y}$ ohm; or

$$R_y = \frac{.00254}{W_y} \qquad (3)$$

where R_y = resistance, in ohms, per yard of rail;
W_y = weight of rail, in pounds, per yard.

Rule I.—*The resistance, in ohms, of 1 yard of steel rail is equal to .00254 divided by the weight, in pounds, per yard.*

Sometimes it is more convenient to have the resistance expressed in terms of 1,000 feet of rail. Since 1,000 feet $= \frac{1000}{3}$ yards,

$$R' = \frac{.00254 \times \frac{1000}{3}}{W_y} = \frac{.848}{W_y} \qquad (4)$$

Rule II.—*The resistance, in ohms, per 1,000 feet of steel rail is equal to .848 divided by the weight, in pounds, per yard.*

If the resistance per mile is desired, we have

$$R_m = \frac{.00254 \times 1,760}{W_y} = \frac{4.48}{W_y} \qquad (5)$$

Rule III.—*The resistance, in ohms, per mile of steel rail is equal to 4.48 divided by the weight, in pounds, per yard.*

It should be particularly noted that these formulas are based on the assumption that the steel has a specific resistance 10 times that of copper.

45. For a special conductor rail with a resistance 8 times that of copper the formulas would become

$$R_y = \frac{.00204}{W_y} \qquad (6)$$

$$R' = \frac{.679}{W_y} \qquad (7)$$

$$R_m = \frac{3.59}{W_y} \qquad (8)$$

In the case of a single track, there are two rails in parallel; hence, the resistance for each unit length of track (two rails) would be one-half that given by the preceding formulas. For a double-track road (four rails in parallel) the resistance would be one-fourth that given by the formulas.

As shown later, under the subjects of rail joints and rail bonding, there is no reason why the resistance measured across, say, 3 feet of rail including a joint should not be as low as 3 feet measured across the solid rail if proper care is taken at the joints. Hence, for first-class construction, it is allowable to take the resistance calculated from the above formulas as representing the actual track resistance without the necessity of adding anything for extra resistance due to joints.

Table VI shows various values of rail and track resistance thus calculated; if provision is not made for thorough bonding, the values given would be exceeded by an amount depending on the conductivity of the joints as compared with an equal length of solid rail.

RAIL SECTIONS

46. Two kinds of rail are in common use for electric railways: **T rails** and **girder rails**; girder rails may be subdivided into two classes: *tram rails* and *groove rails*. There is no good reason why a T rail should not be called a girder rail; it resembles a girder fully as much as the rails commonly known by that name, and this is particularly so with the high T rails now so much used in paved streets.

TABLE VI

RAIL RESISTANCE

Weight Pounds per Yard	Area of Cross-Section Square Inches	Track Rails Resistance of Steel = 10 × Resistance of Copper										Conductor Rails Resistance of Steel = 8 × Resistance of Copper						
		Equivalent Copper Cross-Section Square Inches	Ohms per Yard			Ohms per 1,000 Feet			Ohms per Mile			Equivalent Copper Cross-Section Square Inches	Ohms per Yard		Ohms per 1,000 Feet		Ohms per Mile	
			Single Rail	Two Rails in Parallel	Four Rails in Parallel	Single Rail	Two Rails in Parallel	Four Rails in Parallel	Single Rail	Two Rails in Parallel	Four Rails in Parallel		Single Rail	Two Rails in Parallel	Single Rail	Two Rails in Parallel	Single Rail	Two Rails in Parallel
40	4.0	.40	.0000635	.0000318	.0000159	.0212	.0106	.00530	.1120	.0560	.0280	.50	.0000510	.0000255	.0170	.00850	.0898	.0449
45	4.5	.45	.0000564	.0000282	.0000141	.0188	.00940	.00470	.0995	.0498	.0249	.56	.0000453	.0000227	.0151	.00755	.0798	.0399
50	5.0	.50	.0000508	.0000254	.0000127	.0169	.00845	.00423	.0896	.0448	.0224	.63	.0000408	.0000204	.0136	.00680	.0718	.0359
55	5.5	.55	.0000462	.0000231	.0000116	.0154	.00770	.00385	.0815	.0408	.0204	.69	.0000371	.0000186	.0123	.00615	.0653	.0327
60	6.0	.60	.0000423	.0000212	.0000106	.0141	.00705	.00353	.0747	.0374	.0187	.75	.0000340	.0000170	.0113	.00565	.0598	.0299
65	6.5	.65	.0000391	.0000196	.00000978	.0130	.00650	.00325	.0689	.0345	.0172	.81	.0000314	.0000157	.0104	.00520	.0552	.0276
70	7.0	.70	.0000363	.0000182	.00000908	.0121	.00605	.00303	.0640	.0320	.0160	.87	.0000291	.0000146	.0097	.00485	.0513	.0257
75	7.5	.75	.0000338	.0000169	.00000845	.0113	.00565	.00283	.0597	.0299	.0149	.94	.0000272	.0000136	.00905	.00453	.0479	.0239
80	8.0	.80	.0000318	.0000159	.00000795	.0106	.00530	.00265	.0560	.0280	.0140	1.00	.0000255	.0000128	.00849	.00424	.0449	.0224
85	8.5	.85	.0000299	.0000149	.00000748	.00998	.00499	.00249	.0527	.0264	.0132	1.06	.0000240	.0000120	.00799	.00399	.0422	.0211
90	9.0	.90	.0000282	.0000141	.00000705	.00942	.00471	.00236	.0498	.0249	.0124	1.12	.0000227	.0000114	.00754	.00377	.0399	.0199
95	9.5	.95	.0000267	.0000134	.00000668	.00893	.00447	.00223	.0472	.0236	.0118	1.18	.0000215	.0000108	.00715	.00358	.0378	.0189
100	10.0	1.00	.0000254	.0000127	.00000635	.00848	.00424	.00212	.0448	.0224	.0112	1.25	.0000204	.0000102	.00679	.00339	.0359	.0179
105	10.5	1.05	.0000242	.0000121	.00000605	.00808	.00404	.00202	.0427	.0214	.0107	1.31	.0000194	.00000970	.00647	.00324	.0342	.0171
110	11.0	1.10	.0000231	.0000116	.00000578	.00771	.00386	.00193	.0407	.0204	.0102	1.37	.0000186	.00000930	.00618	.00309	.0327	.0164
115	11.5	1.15	.0000221	.0000111	.00000553	.00737	.00369	.00184	.0389	.0195	.00973	1.43	.0000177	.00000885	.00590	.00295	.0312	.0156

In Fig. 43, (*a*) shows a **T** section, (*b*) a tram girder, and (*c*) a groove girder. In each case, *h* is the *head*, or *ball;* *w*, the *web;* and *f*, the *flange* or *foot*. A **T** rail is a *center-bearing rail*, because the center of the head is directly over the center of the web. The girder rail shown in (*b*) is called a *tram rail* because of the projecting tram *t*; in (*c*), the *groove o* is the distinctive feature; the projecting part *d*

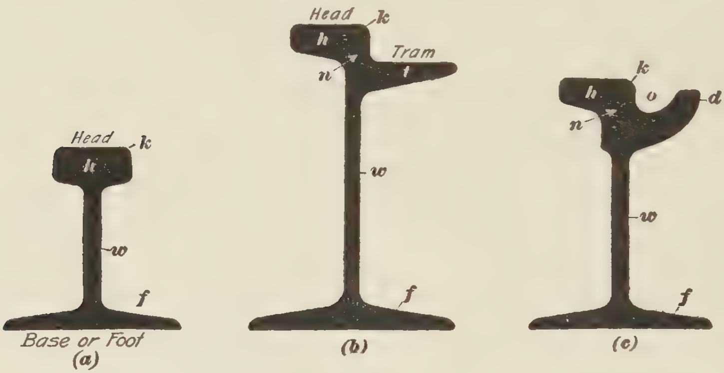


FIG. 43

is called the *lip*. *k* is the *gauge line*, or the part that the gauge touches when gauging the distance apart of the rails. The tram rail is the first in order of invention and it is still more used than any other type of girder rail. The tendency is to use long rails for electric-railway work in order to reduce the number of joints. Ordinary rails are 30 feet in length, but many roads are now using 60-foot rails even though they are more difficult to ship and handle.

47. T Rails.—The **T** rail is used on all steam roads and on electric roads wherever allowable. For suburban and interurban lines, it is the type universally employed; and even for city work in paved streets it is taking the place of the tram and groove rails. The **T** section gives a maximum amount of strength and stiffness with a minimum of material, and it has no groove or tram for the collection of dirt; the head remains clean, and a clean rail means less power for the propulsion of the cars. It is cheaper than the

tram or groove types and provides a track that is easier to lay and is fully as good, if not better, so far as running qualities are concerned. There has always been more or less opposition to the use of **T** rails in paved streets on the ground that they break up the surface of the pavement more than the tram or girder shapes, thus interfering with street traffic. However, with special paving bricks now used this objection is overcome to a large extent, and **T** sections are strongly advocated by many prominent street-railway engineers.

TABLE VII

WEIGHTS AND DIMENSIONS OF STANDARD T RAILS

(*A. S. C. E. Sections*)

Weight Pounds per Yard	Area of Cross-Section Square Inches	Width of Base and Height Inches	Thickness of Web Inches	Width of Head Inches
100	9.8	$5\frac{3}{4}$	$\frac{9}{16}$	$2\frac{3}{4}$
95	9.3	$5\frac{9}{16}$	$\frac{9}{16}$	$2\frac{11}{16}$
90	8.8	$5\frac{3}{8}$	$\frac{9}{16}$	$2\frac{5}{8}$
85	8.3	$5\frac{3}{16}$	$\frac{9}{16}$	$2\frac{9}{16}$
80	7.8	5	$\frac{35}{64}$	$2\frac{1}{2}$
75	7.4	$4\frac{13}{16}$	$\frac{17}{32}$	$2\frac{15}{32}$
70	6.9	$4\frac{5}{8}$	$\frac{33}{64}$	$2\frac{7}{16}$
65	6.4	$4\frac{7}{16}$	$\frac{1}{2}$	$2\frac{13}{32}$
60	5.9	$4\frac{1}{4}$	$\frac{31}{64}$	$2\frac{3}{8}$
55	5.4	$4\frac{1}{16}$	$\frac{15}{32}$	$2\frac{1}{4}$
50	4.9	$3\frac{7}{8}$	$\frac{7}{16}$	$2\frac{1}{8}$
45	4.4	$3\frac{11}{16}$	$\frac{27}{64}$	2

48. For suburban or interurban roads, standard **T** rails similar to those used on steam roads are suitable; no paving conditions have to be met and a rail of standard height can be used. Fig. 44 shows four of the standard sections for **T** rails and fish-plates adopted by the American Society of Civil Engineers and commonly known as A. S. C. E. sections. In all these, the height is equal to the width of the

base; (*a*) is a 100-pound rail; (*b*) a 95-pound; (*c*) a 90-pound; and (*d*) an 85-pound. Table VII gives dimensions of the various A. S. C. E. sections; rails as small as 45 pounds per yard are given in the table, but those lighter than 60 pounds are seldom used for electric-railway work, except perhaps for light railways around industrial plants. Many of

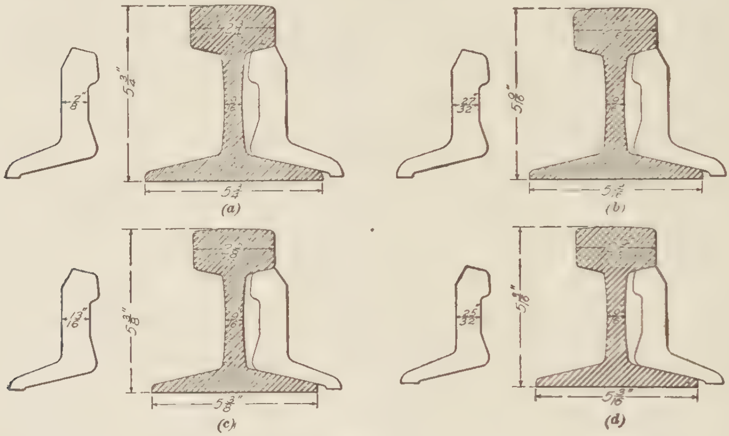
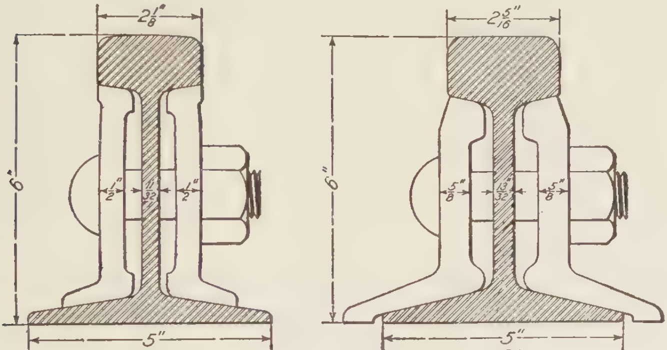


Fig. 44

the leading interurban electric roads use rails of standard A. S. C. E. section, and unless there is some good reason for using a special section it is advisable to install a standard rail wherever possible.

49. When **T** rails are used in paved streets, it is usually necessary to lay a rail higher than the standard; therefore, **T** rails 6 or 7 inches in height are much used for this class of work; they are sometimes called *shanghai rails.* Fig. 45 shows three typical high **T** sections; (*a*) and (*b*) are sections made by the Lorain Steel Company, (*a*) weighing 60 pounds per yard and (*b*) 72 pounds per yard. The one shown in (*c*) is recommended by the Committee on Standards of the American Street Railway Association. It weighs 95 pounds per yard and the distinctive feature is the width of tread, which is 3 inches as compared with $2\frac{1}{8}$ inches in (*a*) and $2\frac{5}{16}$ inches in (*b*). The object of the wide tread is

to allow interurban cars, having a 3-inch wheel tread, to operate over city tracks without interfering with the pavement. The splice bars, or fish-plates, are also made with an unusual amount of camber to prevent buckling when the bolts are drawn up. High **T** rails are strongly recommended,



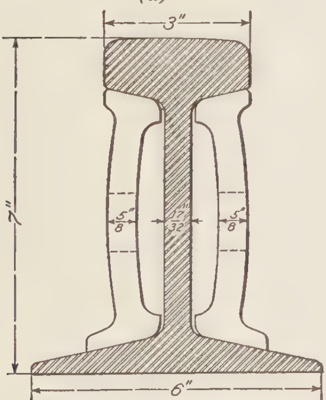


FIG. 45

by the committee just referred to, whenever the consent of the municipality can be obtained.

50. Girder Rails.—Girder rails of the tram or groove type are intended to provide a track that will interfere as little as possible with street traffic. A groove rail leaves the street surface unbroken and there is little tendency for vehicles to run along the rails. The rail head, or groove, does not present an attractive track for carriage or truck wheels, but with the tram rail, the surface of the street is more or less broken and the tram offers a good path for carriages and trucks. The tram rail should not, therefore, be used in places where there is dense city traffic. Vehicle traffic is not of so much importance in localities where it is

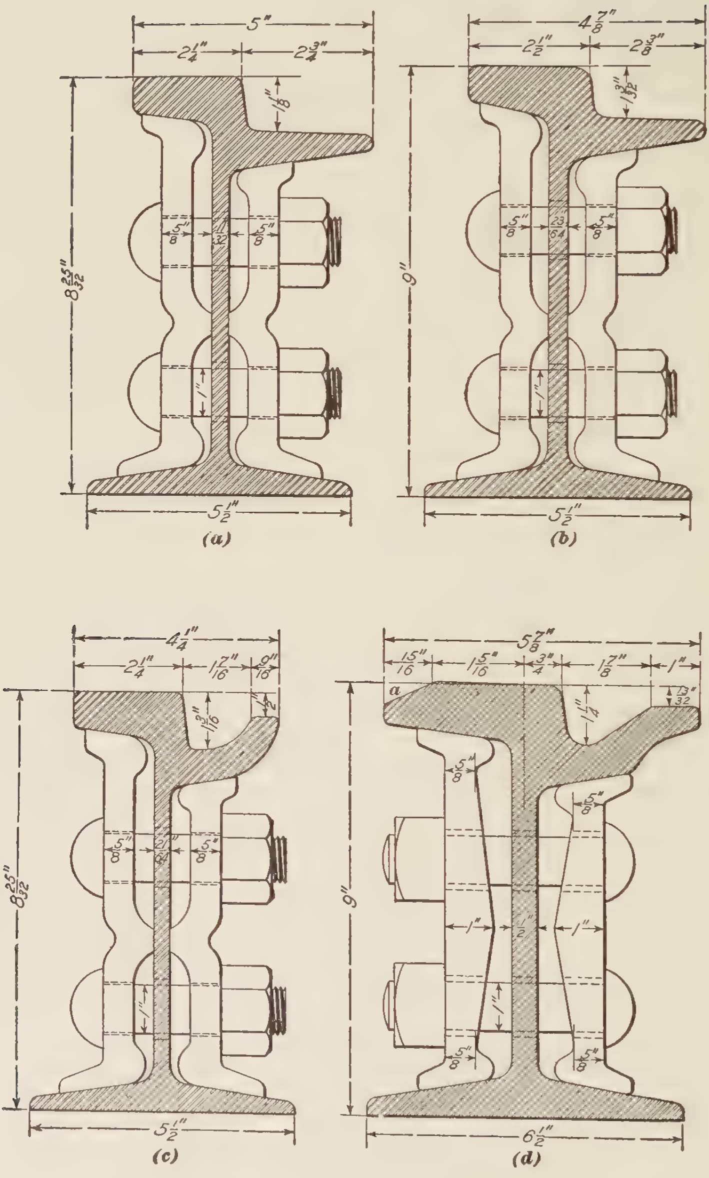

5"
$2\frac{1}{4}$"
$2\frac{3}{4}$"
$8\frac{25}{32}$"
$5\frac{1}{2}$"
(a)
$4\frac{7}{8}$"
$2\frac{1}{2}$"
$2\frac{3}{8}$"
9"
$5\frac{1}{2}$"
(b)
$4\frac{1}{4}$"
$2\frac{1}{4}$"
$1\frac{7}{16}$"
$\frac{9}{16}$"
$8\frac{25}{32}$"
$5\frac{1}{2}$"
(c)
$5\frac{7}{8}$"
$\frac{15}{16}$"
$1\frac{5}{16}$"
$\frac{3}{4}$"
$1\frac{7}{8}$"
1"
$\frac{13}{32}$"
$1\frac{1}{4}$"
a
9"
$6\frac{1}{2}$"
(d)

FIG. 46

not dense, but in large cities the wear on the track from this source may be considerable, and a tram rail not only attracts this traffic but makes it hard for vehicles to turn out of the way. For densely traveled districts, a grooved rail should be used; and for places where the street traffic is lighter, a high **T** rail with special paving bricks next the rail, as described later, will often be found preferable to the tram rail.

51. Fig. 46 shows four girder sections. (*a*) and (*b*) are standard tram sections; (*a*) weighs 90 pounds per yard and (*b*) 94 pounds. Groove rails can only be used satisfactorily where the streets are kept reasonably clean and where the car service is so frequent that dirt or ice does not have a chance to accumulate in the groove. The presence of foreign matter in the groove not only increases the power required to run the car, but also introduces an element of danger, as a small stone may be sufficient to throw the car off the track. It is now customary to make the groove flaring at the top, so that dirt can be pushed out sidewise by the wheel flange. Fig. 46 (*c*) shows an 88-pound grooved girder rail used in Boston. The lip is cut down $\frac{1}{2}$ inch below the tread of the rail, and the section is to a certain extent a compromise between the tram rail and full-groove rail. The groove is wide and flaring so that dirt will be forced out at the side. (*d*) shows a very heavy grooved rail used for standard trackwork in Philadelphia in localities where the traffic is dense. For places where the traffic is lighter, the section shown in (*a*) is used. The rail shown in (*d*) weighs 137 pounds per yard and the lip is extended to the right, as shown, thus combining the tram feature with the groove. Another feature is the way in which the tread is cut off at (*a*), thus helping to keep the part of the tread, on which the wheel runs, cleaner than with ordinary girder rails. For a given groove, there is always a given shape of car-wheel flange that is best suited to that groove; so that in buying car wheels, due regard must be had for the shape and size of the groove that they are to run in, otherwise

there will be excessive wear in the groove and on the wheel flange. A wheel flange must be of a certain depth in order to be safe; if the depth of the groove and the depth of the flange of the wheel are about the same, the least bit of wear in the tread of the wheel will let the weight of the car down on the flange, where it is not intended to be and which will not stand it; if the wheel flanges are deeper than the groove, the wheels cannot be used at all. A track of grooved rail must be gauged to exactness, because it offers two chances for the wheels to bind. If the gauge is too narrow, the outsides of the wheel flanges bind against the heads of the rails; if the rails are too far apart, the insides of the wheel flanges bind against the side of the groove.

52. Standard Track Gauge.—The standard track gauge is 4 feet $8\frac{1}{2}$ inches, as measured by means of a gauge such as that shown in Fig. 47 (*a*). The car wheels are pressed on the axle to 4 feet $8\frac{1}{4}$ inches by means of a gauge similar to that shown in Fig. 47 (*b*). To apply such a gauge correctly, one end of it should be free to move laterally about $2\frac{1}{2}$ inches, when both of the notches engage the flanges of the two wheels. **T** rails are much more economical from the operating point of view than girder rails, because however much the tread of the wheel may wear down or be ground down, there is nothing for the flange of the wheel to ride on.

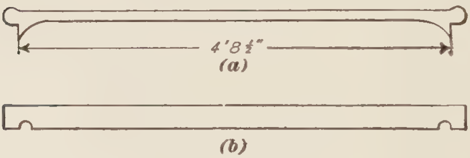


FIG. 47

53. Rails With Conical Tread.—The treads of wheels are conical; that is, the diameter of tread next to the flange is larger than its diameter at the outside edge. This is done to allow the car to center itself on the track when the two wheels on the same axle are of different sizes. The device probably performs its function when there is no greater difference in the wheels than is found on two wheels of the same make just as they come from the foundry; this difference

is, as a rule, not more than $\frac{3}{8}$ inch in the circumference. But the beveled tread cannot be expected to amount to very much as an equalizer where the difference in diameter of the two wheels is $\frac{3}{8}$ or $\frac{1}{2}$ inch. Such a state of affairs should not be allowed to exist, on account of the slippage it causes and for other reasons; but, unfortunately, in some cases it does exist. The general rule has been to make the top of the rail level, with the result that until there is a certain amount of wear in either the rail head or the wheel tread, the traction surface between the two is a straight line. Fig. 48 shows, in an exaggerated way, the point referred to. It is now becoming customary to roll girder rails with a conical tread, as shown in (*b*), thus providing a good traction surface between the wheel and rail from the start, and increasing the life of both by a considerable amount. The rails shown in Fig. 46 (*b*) and (*d*) have conical treads.

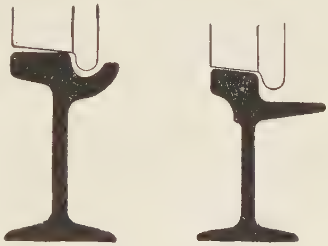

(*a*) (*b*)

FIG. 48

SPECIAL WORK, GUARD RAILS, AND CURVES

54. Special Work.—All roads have a number of crossings, curves, branch-offs, cross-overs, etc., and since these are different from straight track, in that they involve special care and precautions in their installation, they are all included under the general name of **special work**. Important special work is made up complete at the steel works and shipped ready to install. As the construction of special work must be carried out with great precision (a difference of $\frac{1}{4}$ inch in the angle at which one arm of a frog or crossing sticks out may cause no end of trouble), it is done step by step, as follows: The site of the proposed work is first measured up carefully and a drawing of the survey made. This drawing is then carefully checked and is used as a means to lay the work out, in actual size, with chalk on

a hard, smooth, maple floor, known as the laying-out floor; if the job checks up all right, the floor lines and angles are used as a guide for making wooden templets to be used by the patternmaker and the rail bender. When the separate parts of the job are complete, it is set up in the laying-out yard, where any slight errors or inaccuracies due to uneven shrinkage in the cast parts of the job or to want of care in the bending are detected.

55. Designation of Special Work.—Fig. 49 (*a*) shows a *plain curve*, in the sense that it is not complicated by any branch-offs, turnouts, or other special features; such a curve can be simple or compound, single or double, right-hand or left-hand. (*b*) is a *left-hand branch-off* and (*c*) a *right-hand branch-off;* these are used where a branch road leaves the main line. Facing the point of departure of the branch from the main line a right-hand branch-off turns to the right and a left-hand branch-off to the left. (*d*) is known as a *connecting curve and crossing;* in the figure, the curve is a right-hand branch-off to the horizontal straight track and a left-hand branch-off to the vertical one. (*e*) is a *plain* Y; (*f*) is a *three-part* Y; and (*g*) a *through* Y; the three-part Y can be used instead of a loop to turn single-end cars at the end of the line. (*h*) is a *reverse curve*, and must often be used where a cross street is broken at the main street. (*k*) is a *right-hand* and (*l*) a *left-hand cross-over*, used to cross over from one track to the other; these are very convenient devices to place here and there in a main line to turn cars back, either when they are crippled or to get them on their time after a long delay. When it is practicable, a cross-over should be put in so that its switch points will lie in the direction of travel on the two tracks. (*m*) shows a *diamond turnout;* (*n*) an ordinary *siding;* and (*o*), a *thrown-over turnout*, seen very often in temporary work, where it is of the nature of a temporary cross-over to avoid a gang of workmen.

The names given to the different parts of special work vary considerably, and much confusion results therefrom. Fig. 50 shows a piece of special work that includes an example

of nearly all the crossings, switches, etc. commonly met with, and gives the names of the various parts as recommended by the Lorain Steel Company.

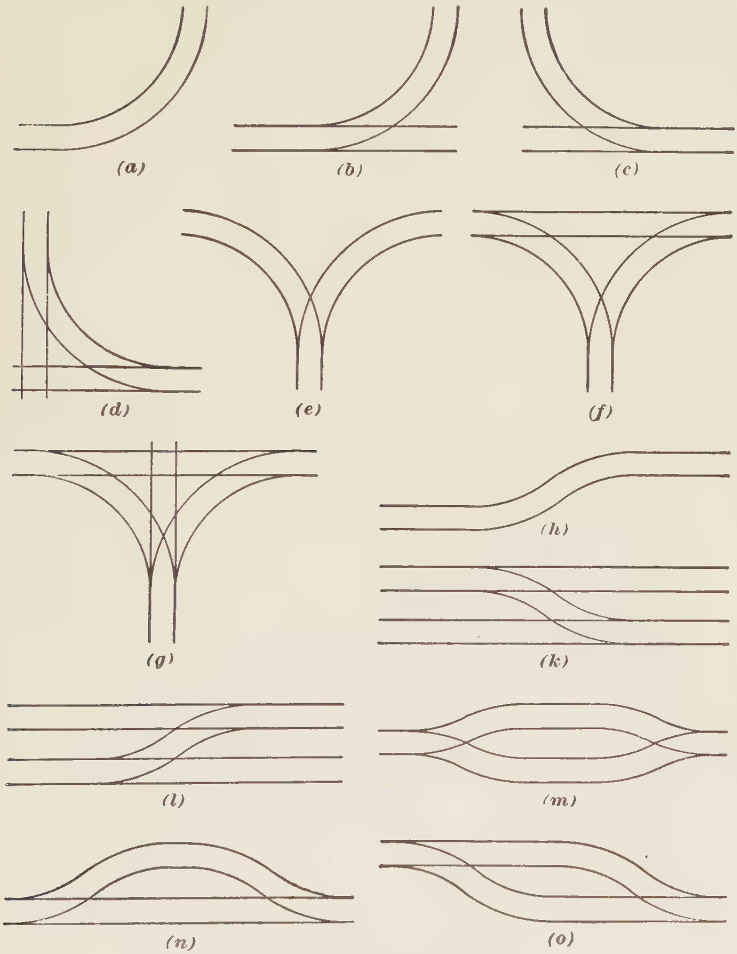


FIG. 49

56. Construction of Special Work.—In the switch, frog, and crossing part of the special work, the greatest wear takes place at the points and breaks, which are subjected to the pounding action of the wheels caused by the

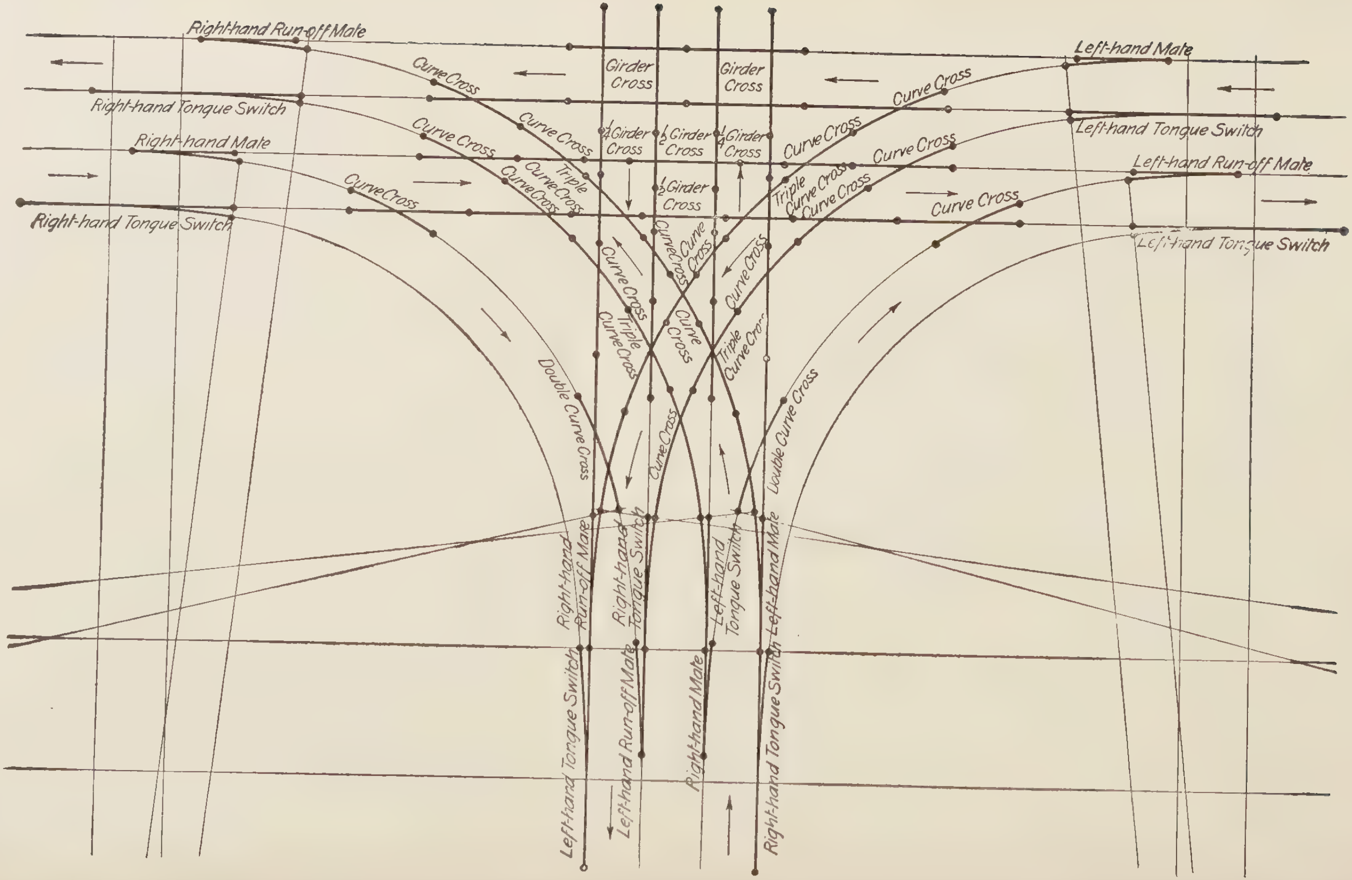

Right-hand Run-off Mate
Right-hand Tongue Switch
Right-hand Mate
Right-hand Tongue Switch
Left-hand Mate
Left-hand Tongue Switch
Left-hand Run-off Mate
Left-hand Tongue Switch
Girder Cross
Girder Cross
$\frac{1}{4}$ Girder Cross
$\frac{1}{2}$ Girder Cross
$\frac{1}{4}$ Girder Cross
$\frac{1}{2}$ Girder Cross
Curve Cross
Triple Curve Cross
Double Curve Cross
Right-hand Run-off Mate
Right-hand Tongue Switch
Left-hand Tongue Switch
Left-hand Mate
Left-hand Tongue Switch
Left-hand Run-off Mate
Right-hand Mate
Right-hand Tongue Switch

FIG. 50

breaks in the tread of the rail. On this account, methods have been adopted for inserting hard steel at the points and crossings. One make of special work, known as *manganese*, takes its name from special plates of hard manganese steel that are placed at the intersections. These are held in place by special bolts, or fastenings, so that they can be renewed

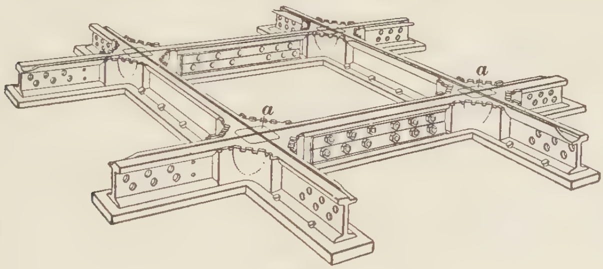


FIG. 51

when worn out. Another class of work is known as *guarantee*, because the crossings are guaranteed to wear as long as the abutting rail. In it, tempered steel wearing plates are held in place by keys, and zinc poured in around the piece. In a

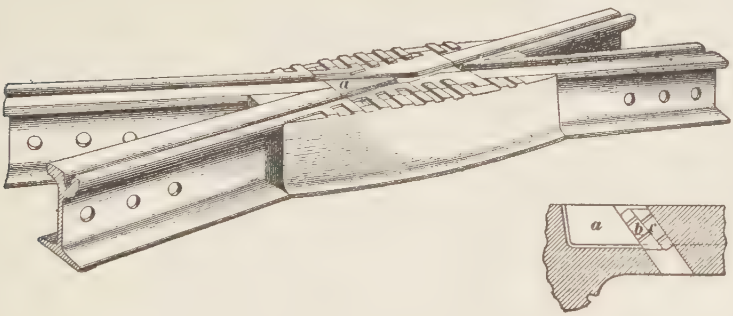


FIG. 52

third class of special work, known as *adamantine*, the crossings are made of steel castings. Fig. 51 shows a crossing of the guarantee type. Renewable hardened steel plates *a*, *a* are set in as shown; the joints are stiffened by a liberal use of cast iron, into which the ends of the rails are cast-welded at the crossings.

Fig. 52 shows a guarantee curve cross, showing how the renewable parts are arranged. The hardened-steel plate *a* is held in place by wedges *b*, *c* that are bedded in zinc, which prevents their working loose. In order to remove the plate, the wedges *b* are driven down.

57. Curves.—Curves are of two kinds, **simple** and **compound**, or **transition**, curves. A simple curve is one that is described with but one radius throughout its length, while a compound curve is one so constructed that the radii become shorter as the middle point of the curve is approached from either end and is easier riding than a simple curve. Street-railway curves are always designated by the radius, in feet, at the center. Long curves of light rail are sprung in, as a rule; that is, the rail is pried over with a bar and spiked into position, the paving being relied on to keep the track in place. The main objection to "springing in" a curve is, that if done on a curve of too short a radius or with heavy rail, the job in course of time will give trouble at the joints; the ends of the rails straighten out and make an angle at the joint. This means that the car trucks in rounding such a curve will change direction in jumps, instead of gradually, and impart to the car a disagreeable, jerky motion not to be found on a curve that is smooth and regular. On curves of heavy rails and moderate radius, a portable rail bender should be used, while shorter curves should be bent to a templet with a power bender. With ordinary **T** rails, curves having a radius of 500 feet or over can be sprung in, but with girder rails or high **T** rails 800 to 1,000 feet is the smallest allowable radius.

58. A very important point about laying out a single-track curve is to be certain that a car will go around it freely without either end overhanging the corner of the sidewalk or striking any obstruction. On double-track curves is also introduced the feature of two cars being able to pass each other without danger. It is not absolutely essential that the curves be such that two cars can pass each other on them, and in many existing cases it cannot be done. Very often,

however, it involves but small additional cost to so construct the curves, and in the long run it is the best thing to do. Whether or not a curve will allow cars to pass on it depends on the following: The length of the car; the width of the car; the amount that the ends overhang the wheel base; the distance between the track centers; the curvature; the elevation of the outside rail; the length of the wheel base; and, on double-truck cars, the distance between trucks. Also, the matter of fenders should be taken into account, as a fender increases the effective length of the car. As the trucks on a double-truck car are relatively nearer the ends of the car, the overhang in the center must be considered. The best plan is to lay out on paper and to scale a plan of the proposed curve; then, by means of a pasteboard dummy that scales the dimensions of the outside lines of the car, the actual clearance at all points can be readily determined. The positions of the car wheels may be indicated by holes through which the track can be seen, or transparent paper may be used, so that the dummy can be made to take the right path around the curve. Another point to be looked after in cutting out a dummy is to see that the widest part of the car is represented. To insure some degree of safety to the heads and arms of passengers, the clearance on both sides of the car should be at least 12 inches, if they are to pass each other on curves. Special attention must be paid to this feature where the center-pole method of line construction is used. There are many roads on which the curve clearance is not over 2 or 3 inches, but in most of such cases there is a rule against passing on curves.

59. Transition, or Compound, Curves.—These curves are formed by combining curves of different radii, so that the entrance of the car into the curve shall be gradual, and a sudden shock avoided. The curve at the point where it branches from the straight part of the track, or a tangent, as it is called, is of long radius and the radii are gradually decreased until the radius of the center of the curve is reached. Theoretically, the correct method would be to

make a true spiral connection between the tangent and the center of the curve, but this would be impracticable. Steel companies making a specialty of trackwork for electric railways have developed standard transition curves that approximate a spiral sufficiently close for all practical purposes. For example, the Lorain standard curve for a radius at the center of the curve varying from 40 feet to 62 feet 6 inches has an entrance radius of 432 feet.

At one time, curves for electric railways were made up of arcs of different radii struck from three or five different centers, thus giving a rough approximation to a spiral. Curves as now used are made up of a number of radii such that the length of arc of any one radius is not over 5 feet. This gives a curve that is practically as smooth riding as a true spiral.

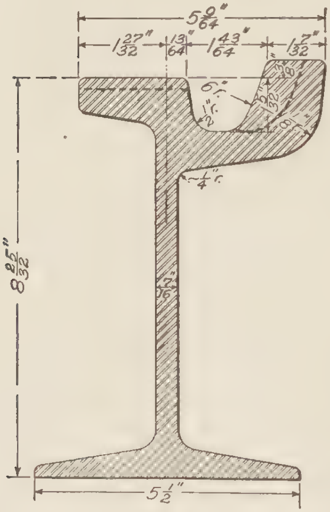
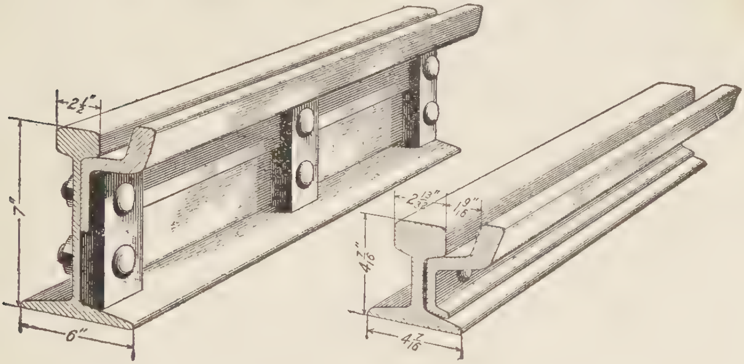


FIG. 53

60. Guard Rails.—Guard rails are rails provided with a protecting flange to prevent a car from climbing the rail on a curve; they may be solid or built up. Girder rails are, as a rule, solid; **T** rails are built up. Fig. 53 shows a section of a girder guard rail. It resembles a groove rail very closely except that the lip is heavier and projects above the tread of the rail. There is always considerable wear on the side of the groove and in time the lip and tread become worn, as shown by the dotted line. The **T** rail need only be provided with a regular guard where it is used in a paved street. In country work, the steam-road practice of laying a second line of **T** rail next to the inside-track rail is adopted. This practice is also adopted, as a rule, on bridges, where the guard rail is laid beside both track rails. The best authorities are inclined to the belief that a guard rail on

the inside, or short rail, of a curve affords ample protection, but it is common to see a guard on both the inside and outside rails of short curves. At any rate, it is not safe to rely on the wheel flanges alone to keep the car on the track, for



(a) (b)

FIG. 54

car wheels in street-railway service, on account of the heavy weight attached to the axle and also on account of the nature of the special work that they have to jolt over at times, are addicted to the trouble of broken or chipped flanges. A wheel with such a defect in the flange is almost certain to climb the rail if that wheel is on the front end of the car as a leader. As in the case of an ordinary grooved rail, a great deal of judgment must be used to select a groove that is adapted to the flanges of the wheels used. Fig. 54 shows two methods of attaching rail guards to **T** rails, (*a*) being used for high **T** rails and (*b*) for an ordinary rail, in this case a standard 65-pound A. S. C. E. section.

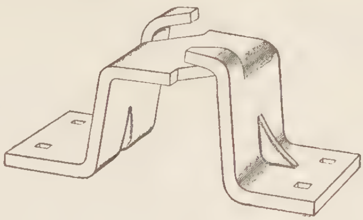


FIG. 55

61. Rail Chairs and Braces.—When a rail is not deep enough to accommodate the paving in a street, it can be raised on **chairs**. These are forged fittings on which the

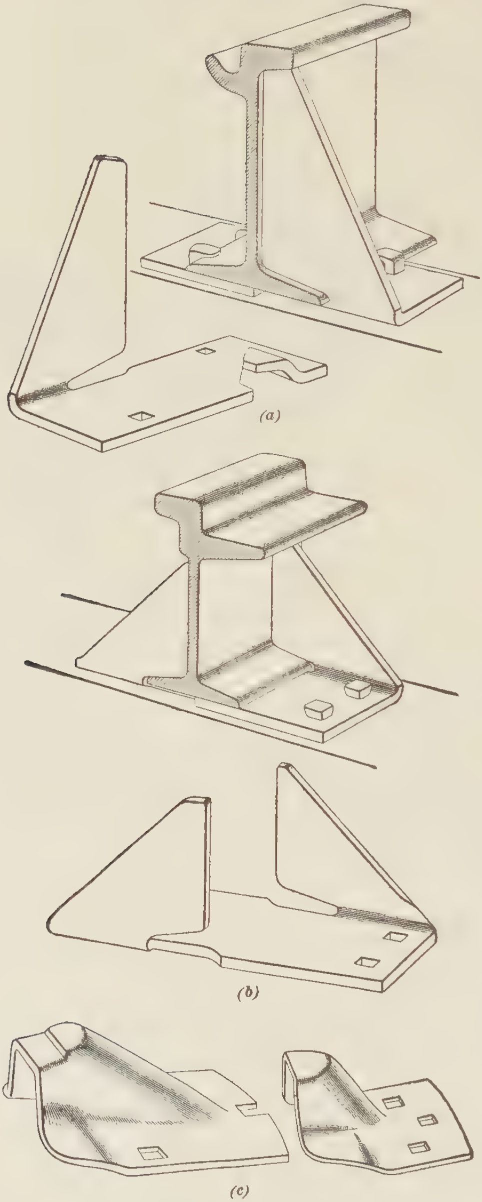


FIG. 56

rail rests and which raise it to the desired height. Fig. 55 shows a common form of chair.

In order to keep the track from spreading, either **tie-rods** or **braces** may be used. The former consist of rods threaded on each end; the most common form is $1\frac{1}{2}$ inches by $\frac{3}{8}$ inch forged $\frac{3}{4}$ inch round on the ends and threaded. The threaded ends pass through the webs of the rails and the track is held to gauge by nuts screwed up against the webs.

The track can also be held to gauge by means of tie brace plates that bear against the outside of the rail. These are, by many, considered a very much better form of fastening than tie-rods because they support the head of the rail and do not tend to cant the rails. They are particularly useful for holding rails to gauge on curves. Fig. 56 shows three common styles of forged brace plates, the small plates shown in (*c*) being designed for **T** rails.

LINE AND TRACK
(PART 2)

RAIL JOINTS

1. No part of electric-railway track construction calls for greater care than the track joints; in fact the life of a track is in most cases limited by the life of the joints. If there is the slightest unevenness or looseness, the pounding action soon flattens the rails at the ends and matters rapidly go from bad to worse. Again, poor joints usually imply poor electrical connection between abutting rails so that in

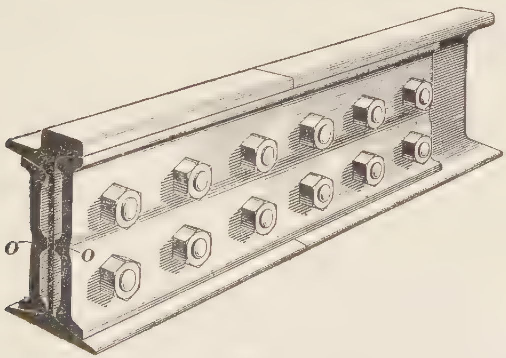


FIG. 1

electric railways, where the track is used as one side of the circuit, good joints are of even greater importance than on steam roads. Electrical contact may be made between the rails by means of copper bond wires or other bonding appliances, but if the joint is not good mechanically the continual movement and jarring will, sooner or later, impair the bond contacts. A great many kinds of rail joint have been

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devised, but it will be possible to describe here only a few of the more important ones.

2. Fish-Plates or Splice Bars.—Fig. 1 shows a standard 12-bolt joint made with two **fish-plates, splice bars, joint plates,** or **channel plates,** as they are variously called. The plates are provided with projecting ribs *O*, *O*, to prevent buckling when the bolts are drawn up, while flanges at the top and bottom bear against the under side of the head and tram and the upper side of the foot, thus adding to the stiffness of the joint.

3. Base-Supporting Joints.—In order to provide additional strength and stiffness, a number of rail joints have been devised which, in addition to the support furnished by well-fitting joint plates, provide additional support under the foot of the rail. They are somewhat higher in first cost than ordinary splice bars, but they furnish a strong joint and are much used.

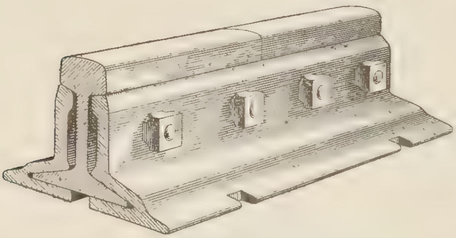


FIG. 2

Fig. 2 shows the **continuous joint,** which is made of rolled sections so shaped that a flange projects under the rail from each side, thus adding to the stiffness and holding the abutting rail ends firmly in line. Fig. 3 shows the **Atlas joint** made of ribbed steel castings; in addition to the usual rail bolts, it has two bolts on the under side. Fig. 4 shows

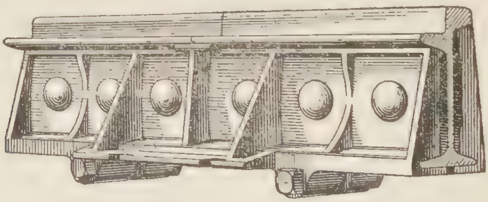


FIG. 3

the **Weber joint;** it is made of two channel plates very similar to those ordinarily used, while in addition a rolled angle is bolted on one side and projects under the foot of the rail. The space between the angle iron and splice bar is filled with a piece of well-seasoned Southern pine that provides a certain amount of elasticity and thus takes up the looseness due to wear on the bearing surfaces of the channel plates caused by small relative movement between the plates and rail.

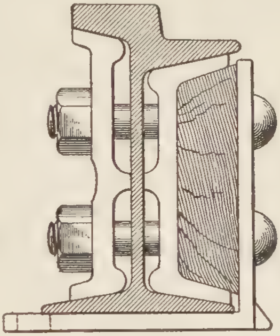


FIG. 4

4. Rail Expansion.—Rails are subjected to considerable variations in temperature, which cause corresponding changes in their length. On ordinary steam roads or on electric roads run where there is no paving, expansion is allowed for byplay in the track bolts. Thus, in cold weather there will be a gap of perhaps $\frac{1}{4}$ to $\frac{5}{16}$ inch between the rail ends while in warm weather there will be scarcely any space at all. Mild steel expands .0000065 of its length for each degree Fahrenheit increase in temperature. Assuming that the extreme difference in temperature that the rail is subjected to is 100° F., a track would be $.0000065 \times 100 = .00065$ of its length longer in the hottest weather than in the coldest.

A stress of 1,000 pounds per square inch will stretch a mild steel bar .00003 of its length. Hence, if a rail is stretched .00065 of its length, the stress in the rail will be $\frac{.00065}{.00003} \times 1{,}000 = 21{,}666$ pounds. If the rails are continuous and firmly anchored so that there is no play at the joints, the track as a whole must expand and contract. The rails will expand with increase in temperature, thus causing compressive stresses; and on contracting with decrease in temperature, the rails will be stretched but the stresses so caused will not exceed 22,000 pounds per square inch under the conditions assumed. A safe value for the elastic

limit of steel is 40,000 pounds per square inch; i. e., steel subjected to any stress below this amount will not take a permanent set but will return to its original length when the stress is removed. If, therefore, a track is located so that it cannot buckle sidewise and get out of line, there is no objection to butting the ends of the rails together and fastening them by means of some form of joint that allows no longitudinal motion whatever. In paved streets this condition is met and it is now a very common practice to use methods of rail joining that give a continuous rail.

In paved streets, the rails are not subjected to such rapid or extreme variations of temperature as on open tracks, because the paving equalizes the temperature to a certain extent. There are a number of types of solid joint, the most important being the *cast welded*, the *electrically welded*, the *thermit*, and the *zinc*. The use of these is confined to paved streets, in cities, where the rails cannot get out of alinement and where the traffic is heavy enough to warrant the expense of such joints. For open trackwork they are not allowable, because provision must here be made for expansion and, even neglecting this, the expense of solid joints would be too great in most cases.

5. Cast welded joints are made by molding cast iron around the abutting ends of the rails, which are first thoroughly cleaned for a distance of 6 or 8 inches, on each side of the joint, by means of a sand blast. A cast-iron mold is then clamped around the rail ends and iron poured in, thus forming a joint, as shown in Fig. 5, where l is the cast iron molded around the rail ends. In order to make these joints, considerable apparatus is required—a portable cupola is needed for melting the iron, and there must also be a sand blast for

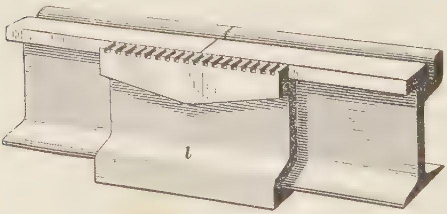


Fig. 5

cleaning the rails. To make the joints at all reasonable in price, a large number must be done at a time. The weight of iron varies from 70 to 225 pounds, depending on the shape of the joint and the section of the rail.

Fig. 6 shows one form of Falk joint; the sides of the cast-iron part are straight, thus making the joint much easier to pave around than when the sides are curved. The weight of iron in the joint shown in Fig. 6, which represents one of the heavier types, is about 170 pounds. In cast welding, the iron is poured at high temperature and it appears to fuse into the surface of the steel rail, thus forming a joint that is strong mechanically and of high conductivity. The conductivity of the joint, as compared with an equal length of rail, depends to

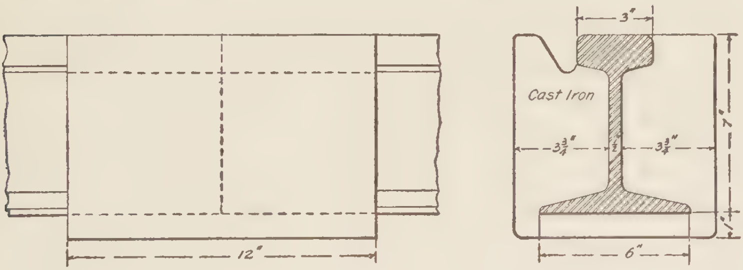


Fig. 6

some extent on the amount of iron used. In some cases the joint resistance may be about 10 per cent. higher than that of a corresponding length of rail, while in others numerous tests have shown that the resistance is as low or even lower than that of the rail. It is claimed by some that cast welding anneals the ends of the rail, thus softening them and causing them to pound or flatten out more than the rest of the rail; but on a number of roads where the cast welded joint has been used for several years no bad effects from this source have been noted.

6. Electrically Welded Joint.—The method of making electrically welded joints as carried out by the Lorain Steel Company consists in welding bars to each side of the web of the rail by passing a very large current through the bars and

rail. Quite an elaborate outfit is required for this process and, like cast welding, it is only applicable where a large number of joints are to be made. The outfit consists of four cars: first, a sand-blast car; second, the car carrying the welder; third, a car attached to the welding car and carrying the transforming apparatus for supplying the welder with current; fourth, a car provided with machinery for grinding off the rail treads after the joints have been welded; the cars are arranged in the order named. The first car contains a sand-blast tank and a motor-driven air compressor for operating the blast by means of which the web of the rail and the surfaces of the plates are thoroughly cleaned before the welding action takes place. To make the joint, a mild-steel plate, similar to that shown in Fig. 7, is welded on each side of the web; the finished joint appears as shown in Fig. 8. Each bar is welded in three places corresponding to the raised parts a, b, c, Fig. 7. The bosses a, b at the ends of the bar are formed under a drop hammer, which forces the metal in on one side and out on the other, the depression in one side being afterwards filled with a piece of metal. The boss at c, which comes opposite the joint between the rails, is made by placing a small strip of steel over the bar. The object of the bosses is to localize the welding current and thus confine the welding to a certain area; each boss has an area of about $3\frac{1}{2}$ square inches so

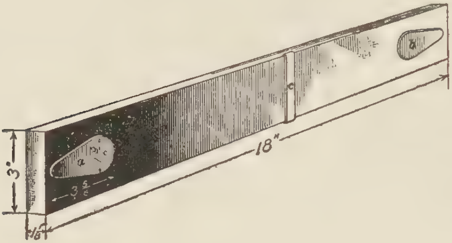


Fig. 7

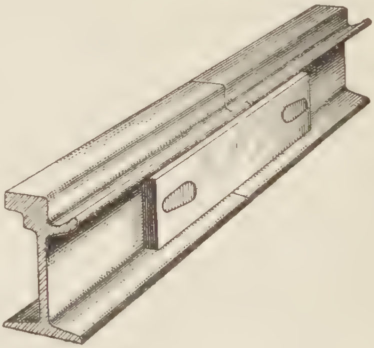


Fig. 8

that the welded area on each bar is about $10\frac{1}{2}$ square inches, or 21 square inches for the two bars. After the rails have been cleaned, lined up carefully, and the bars wedged in position, the joint is ready for welding by means of the electric welder suspended from the front of the second car.

7. The operation of welding will be understood from Fig. 9, which shows the main parts of the welder and their relation to the joint. The two splice bars *a*, *a* are located so that the center boss comes opposite the end of rail *b*. The terminals *c*, *d* of the welding transformer *e* are pressed against the splice bars by means of levers *f*, *g* that are pushed apart at their upper ends by pistons working in a hydraulic cylinder *h*. Just sufficient pressure is applied to hold the bars in place and provide good contact. The secondary of the transformer consists of a single loop of very heavy conductor, so that a very large current at low pressure is delivered. The whole welding apparatus is suspended from a yoke *k* carried by an arm *l* extending from the front of the car and arranged so that the welder can be moved in any direction to permit an easy and rapid adjustment to the joint. The primary of the transformer is supplied with alternating current obtained from a rotary converter located in the third car and driven by direct current from the trolley. Suitable regulating devices are provided so that the voltage applied to the welder can be maintained fairly constant, even though the trolley voltage varies considerably.

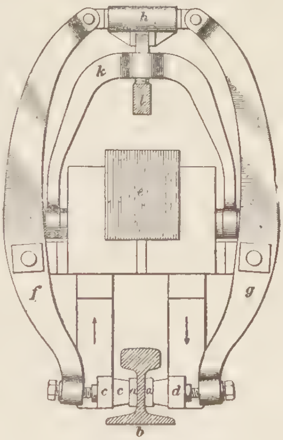
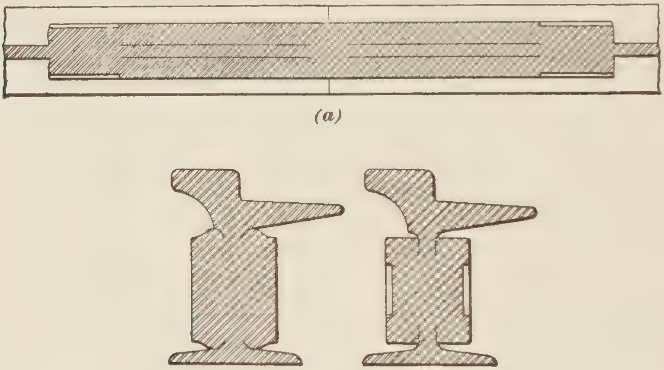


FIG. 9

The weld in the center of the bars is made first. In about $2\frac{1}{2}$ minutes after the current is turned on, the joint is brought up to a welding heat; the current is then cut off and the pressure on the joint increased by the hydraulic cylinder *h*,

the total pressure applied being about 37 tons. After a few moments, the pressure is released and the welder adjusted to one of the end welds where the process is repeated, only with both end welds, the heavy pressure is maintained until the metal has cooled below a glowing heat; it has been found that this makes the weld tougher. Since the middle weld is made first, the bars become expanded because of the heat, and since the end welds are made before the middle weld has cooled off, the ends of the bars are fastened to the rail while the metal is expanded. Hence, as the bars cool, the ends of the rail are pulled together, thus making a very close joint.



(a)

(b) (c)

Fig. 10

Fig. 10 (*a*) shows a horizontal section of a completed joint; (*b*) and (*c*) show vertical sections, (*b*) being a section of the center weld and (*c*) of an end weld.

The current supplied to the primary is transformed to a secondary pressure of 7 volts, approximately. The secondary current used for a weld is about 25,000 amperes. The secondary voltage, however, drops somewhat when this large current is flowing so that the power actually taken from the line is not as great as $25,000 \times 7 = 175$ kilowatts. As a general rule, about 125 kilowatts for $2\frac{1}{2}$ minutes is sufficient for welding an ordinary joint. On the average, about 80 joints can be made in 24 hours; as a continuous process, working day and night, it takes from 13 to 15 minutes per joint.

8. Numerous tests show that an electrically welded joint of this construction has a resistance less than that of a corresponding length of rail. Table I shows the results of some tests made by the General Electric Company. The rails were a standard 6-inch girder type, about 6.7 square inches in area, and splice bars similar to those just described were used.

TABLE I

RESISTANCE OF ELECTRICALLY WELDED RAIL JOINTS

Joint Number	Resistance Over Joint Ohms	Resistance Over Equal Length of Rail Ohms	Per Cent. Conductivity of Joint Compared With Solid Rail
1	.00001675	.0000279	166.29
2	.00001625	.00002636	162.2
3	.0000182	.00002785	156
4	.0000168	.00002292	136.26
5	.00001559	.0000233	144
6	.00001602	.0000278	177
7	.00001457	.0000238	159
8	.0000196	.0000266	125

The electrically welded joint is very strong, and rails seldom pull apart at the point of welding. Also, the head of the rail is not made hot enough to soften it, and the splice bars do not interfere with the paving.

9. Thermit Joint.—A method of making solid rail joints that has recently come into use is the **thermit process,** invented by Dr. Hans Goldschmidt. It has shown remarkably good results and gives a joint equal to the rail in conductivity. Careful measurements have shown that the wear at the joints after a year's service does not exceed, appreciably, the wear on the rail.

Thermit is a mixture of finely divided iron oxide and aluminum. The metal aluminum has a great affinity for oxygen, and if this mixture is given a local initial heating

by so-called "ignition powder," a very rapid chemical reaction takes place throughout the whole mixture, and a large amount of heat is liberated. The iron oxide gives up its oxygen to the aluminum and aluminum oxide is formed; at the same time the iron oxide is reduced to pure iron. The heat produced by the reaction is so intense that the mass of molten iron has a temperature of about 3,000° C., and if poured around a rail joint a perfect weld will result.

The appliances required for making a joint by this process are very simple and easily moved from place to place; the cost per joint is practically the same whether a few or many are made, and in this respect the process possesses an advantage over cast welding and electric welding, which are practically out of the question if only a few joints are to be made.

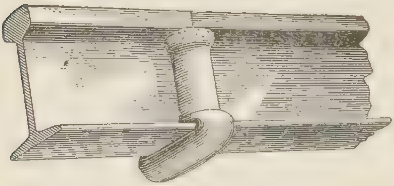
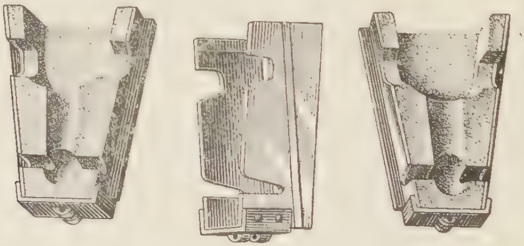


Fig. 11

10. Fig. 11 shows a rail joint made with thermit, and Fig. 12 shows the molds that are clamped on either side of the rail to receive the melted metal. These vary in form according to the shape of the rail section, and are made by placing a sheet-iron case (*b*) over a model, or pattern, of the joint



(*a*) (*b*) (*c*)

Fig. 12

and tamping it full of a mixture of china clay and loam; (*a*) and (*c*) show the molds for the two sides of a rail. The edges of the mold are smeared with clay, so as to form a

tight joint, and the halves are then clamped into position, the ends of the rails being first carefully lined up. The thermit compound is placed in a cone-shaped crucible mounted on a tripod directly over the mold; from 15 to 20 pounds is used for each joint, depending on the size of the rail. The crucible is made of an iron case lined with magnesia, and the bottom is formed of a hard magnesia stone provided with a renewable outlet that will stand from nine to ten runs. The hole in the outlet is stopped by a plug. Dirt on the rail ends is cleaned off by means of a scratch brush, and it is not necessary to use a sand blast. A small amount of ignition powder is placed on top of the thermit and lighted by means of a match; in a few seconds the chemical reaction is over and the lower part of the crucible contains a mass of liquid steel at very high temperature, while the slag (aluminum oxide or corundum) floats on top. The crucible is then tapped by knocking the plug in the bottom upwards and the steel runs into the mold in a $\frac{1}{2}$-inch stream. The weight of steel obtained from the reaction is one-half the weight of the thermit mixture. The mold is made so that the metal strikes the under part of the rail first and works its way up to the top, thus carrying up any dirt or slag that may be present. The steel is so extremely hot that it alloys instantly with the ends of the rail and substances, such as manganese or silicon, are generally incorporated in the thermit mixture, so that the steel has approximately the same composition as the rail. After a few seconds, the metal becomes solid and the molds may be removed.

11. Zinc Joint.—This joint, Fig. 13, is used on a large scale in Philadelphia, and is the invention of Messrs. C. B. Voynow and H. B. Nichols. The channel plates *a*, *a* are similar in their general shape to those used for the continuous rail joint, Fig. 2, except that there is a space left around the foot of the rail and between the upper flanges of the channel plates and the under side of the tram and head of the rail. The rail ends and plates are cleaned with a sand blast, after which the latter are bolted in position by two temporary

bolts and the holes reamed to a uniform size of $1\frac{1}{32}$ inches by means of a portable pneumatic reamer. The plates are then fastened by twelve 1-inch steel rivets driven by a pneumatic riveter. The riveting process expands the rivets so that the holes are filled tightly. Clamps are then put in position to hold asbestos cloth pads that cover the bottom and ends of the plate; the spaces between the head and tram and plates are calked temporarily with asbestos cloth. The whole joint is then heated by means of portable fuel-oil burners until the temperature is raised to 300° or 400° F., after which molten zinc is poured through a 1-inch hole located in the center of the foot of the plate; space *b* is

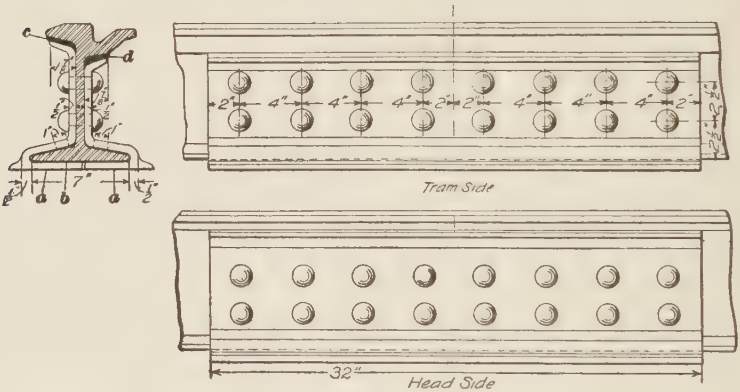


FIG. 13

thus filled with zinc. Dams made of castings padded with asbestos cloth are then arranged around the top of the rail, and spaces *c*, *d* also filled with zinc. This makes a very rigid joint, which allows none of the slight rubbing action that occurs in all bolted fish-plate joints and which sooner or later loosens them. Since the iron surfaces are first thoroughly heated, the zinc attaches itself to the clean iron surfaces, which become galvanized, thus forming a very good electrical contact. Tests have shown that the resistance, after 2 years of continuous use under heavy traffic, is less than that of an equal length of rail. From $22\frac{1}{2}$ to 26 pounds of zinc is required for a joint similar to that shown in Fig. 13.

Outside of the cost of the zinc and the labor of preparing the joint and pouring the metal, the cost of this joint is little more than that of an ordinary one with bolted channel plates.

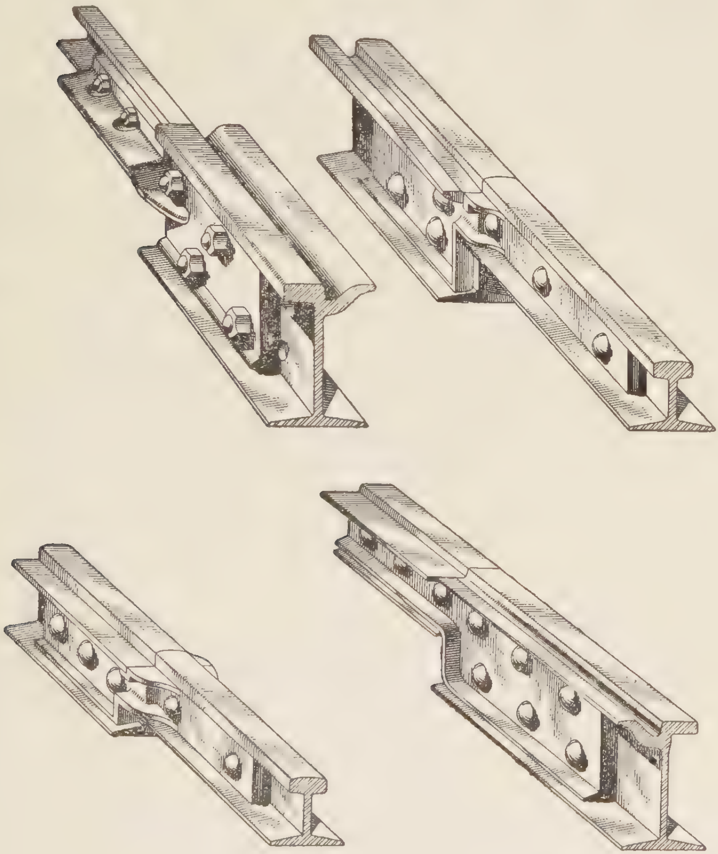


FIG. 14

12. Combination Joints.—Where a rail of one section is to be joined to another of different section, a **combination joint** is used; these can be made by using either special splice bars or by means of a section of special rail in the form of a steel casting. Fig. 14 shows four combination

joints where T rails are joined to girder rails; the special splice bars may be forged or made of cast steel.

Fig. 15 shows three forms of combination rail of cast steel. These can be obtained in any desired length and are joined to the other rails by means of standard joints. This

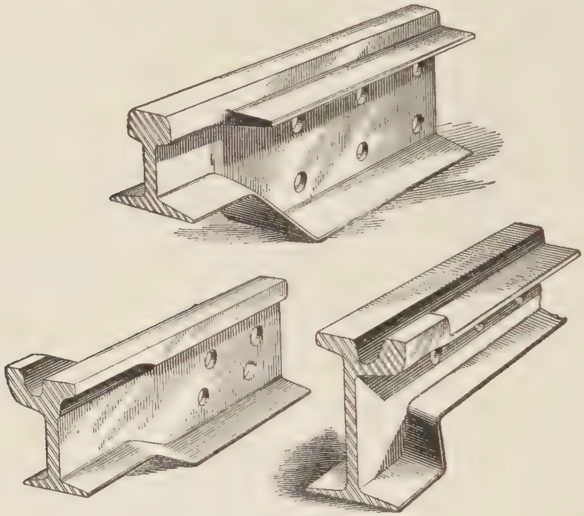


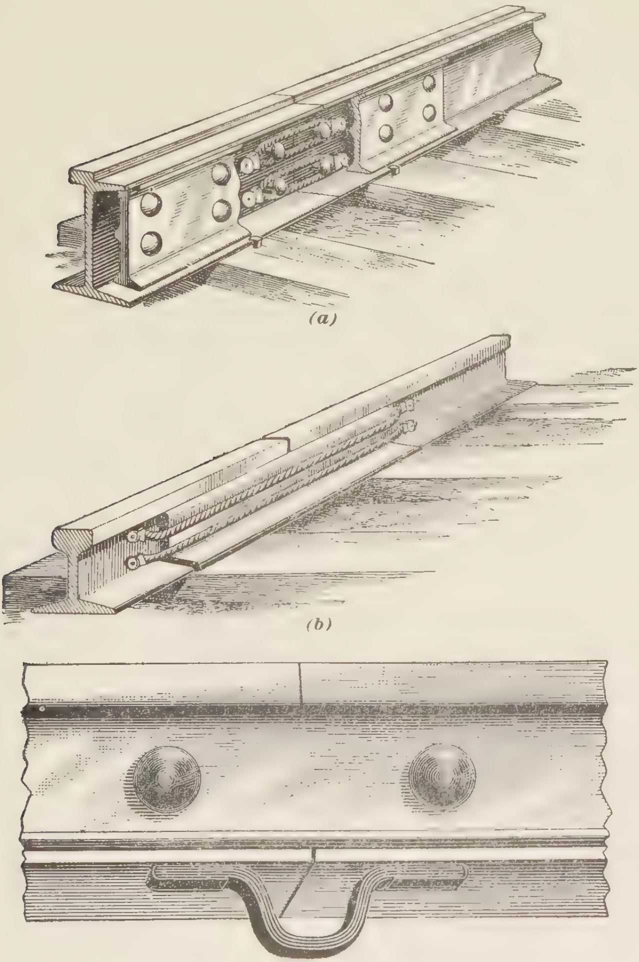
FIG. 15

makes a much better and more substantial construction in every way than the joints shown in Fig. 14, and combination rails are now used in preference to the older construction in the best grades of trackwork.

RAIL BONDS

13. When tracks are not surrounded by paving or when any of the various types of solid joint are not considered practicable on account of cost, the ordinary fish-plates must be supplemented by connections, or **rail bonds**, that will carry the current from rail to rail. The fish-plates cannot be depended on to carry the current, because they soon become loose or rusty and offer a high resistance. A great many styles of rail bond are in use so that it will be possible to describe here only a few typical examples. No matter what

type is used, it must always be remembered that if a joint is mechanically poor, the continual movement and pounding



(a)

(b)

(c)

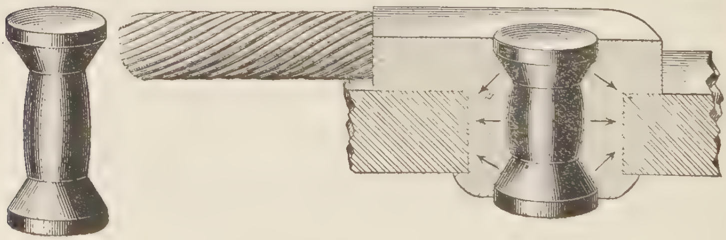
FIG. 16

will sooner or later decrease the efficiency of the bond. It is highly important therefore that the joints be kept in good condition.

If a track is poorly bonded, there will be a continual loss of power due to the resistance at the joints. Low voltage caused by this excessive loss will have its effect on the car equipments, because in order to maintain the schedules the motors will have to be forced and the current per car will be increased. In some cases it may not be possible to maintain the schedules, thus causing a loss of business. Also, if the return circuit is poor, current will come back through neighboring pipes, and trouble on account of electrolysis will result, as described later.

14. Rail bonds may, for convenience, be divided into two general classes—*protected* and *unprotected*. **Protected bonds** are so called because they are placed in the space between the channel plate and rail, as shown in Fig. 16 (*a*); **unprotected bonds** either span the fish-plate, as shown in (*b*), or are fastened to the under side of the rail, as in (*c*), in case there is nothing to interfere with the bond projecting on the under side.

15. Bonds of the protected type are used in cases where there is sufficient space for them between the fish-plate and rail, but with **T** rails the space is often not large enough. They may be made considerably shorter than the unprotected type and they do not offer much inducement to copper



(*a*) (*b*)

FIG. 17

thieves; on the other hand, short bonds less than 6 inches in length are liable to give trouble from breakage. The bonds shown in Fig. 16 (*a*) and (*b*) are of the General Electric type, made by casting copper terminals on a stranded copper conductor. The copper is cast around

an iron plug of the form shown in Fig. 17 (*a*), and after the terminal has been fitted in the web of the rail the plug is compressed to the form shown in (*b*), thus forcing the metal out against the wall of the hole, as indicated by the arrows, and providing a very firm contact between the terminal and rail. The bond, Fig. 16 (*c*), is made of thin copper strips soldered together at the ends so as to form solid terminals, which are attached to the rail by soldering. It has been found in some cases that soldered bonds deteriorate when they are in contact with damp earth.

16. Fig. 18 shows a protected bond of the *double-loop type* shaped so as to give flexibility and at the same time allow openings for the track bolts. It is made of thin copper strips on which copper terminals have been cast. After the terminals *a*, *b* have been passed through the holes in the rail, they are compressed by a special screw compressor that forces the metal out sidewise.

Fig. 19 shows the construction of an *all-wire rail bond* that is made up of copper cable cut to length; the ends are then cold pressed as shown, and afterwards brought to a welding heat and forged to their final shape.

Fig. 20 shows the method of attaching *crown bonds*. A steel pin is driven into a hole in the terminal lug, thus expanding the metal.

17. Solid Copper Protected Bonds.—Very satisfactory results in rail bonding have been obtained by using solid plates pressed firmly against the rail web, the contact surfaces being first thoroughly cleaned and coated with copper-mercury amalgam of about the consistency of putty, which adheres to the surfaces and makes a connection of very low resistance. Fig. 21 shows an *Edison-Brown solid bond;* a copper plate *a*, about 3 in. $\times$ $1\frac{1}{2}$ in. $\times$ $\frac{1}{8}$ in. (the exact dimensions vary with the style of rail to be bonded) is held tightly against the rail when the fish-plates are bolted up. Plate *a* has two depressions and two corresponding bosses on the opposite side, that form the contact surfaces; the plate is covered by a thin steel sheet *b* against which a

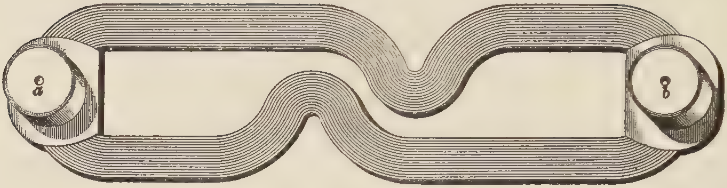


FIG. 18

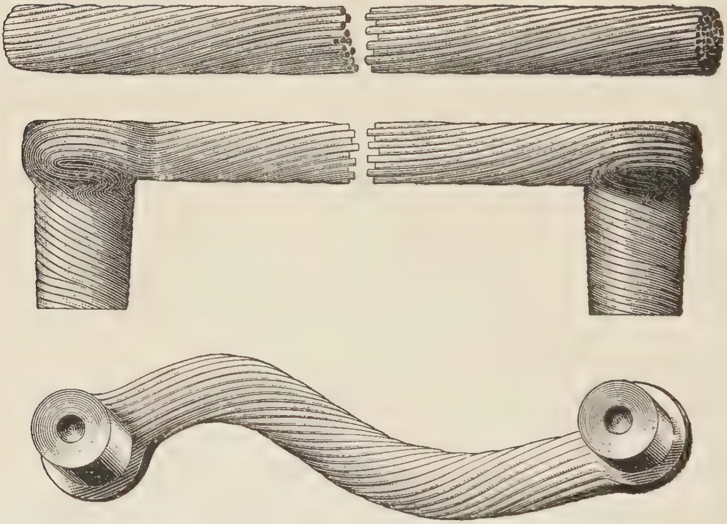


FIG. 19

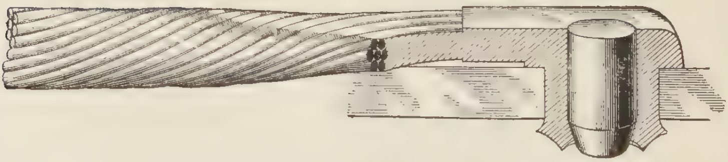


FIG. 20

spring washer *c* bears. The rail is first brightened by means of an emery wheel and the contact surfaces then amalgamated and covered with a thin layer of the alloy. The plate is surrounded by a cork *d*, treated with linseed oil, which, when compressed by the fish-plate, forms a seal around the bond that remains tight even when the fish-plate is loosened considerably. Joints made with amalgam have, after several years of operation, been taken apart and the contact surfaces found to be as bright as when first installed.

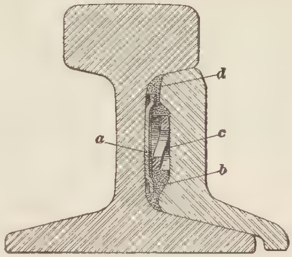


Fig. 21

The *Ajax* solid copper-plate bond, Fig. 22, consists of a piece of copper *a* protected by a steel sheet *b* against which bear cup-pointed setscrews *c*, *c* tapped into plate *d*. The contact surfaces on the rail are

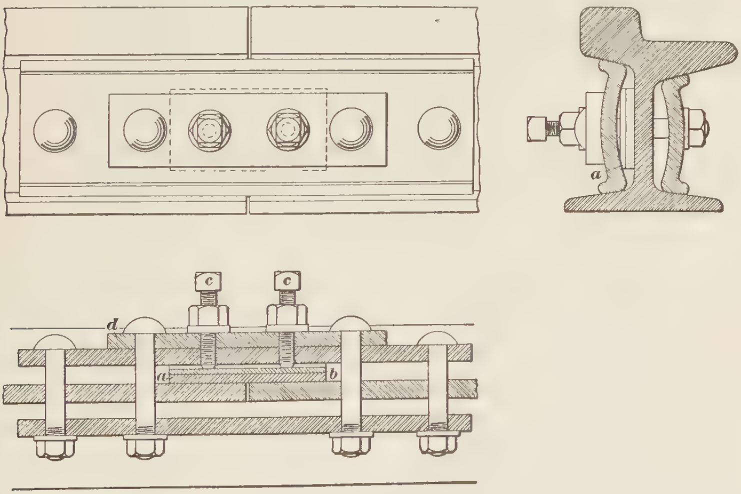
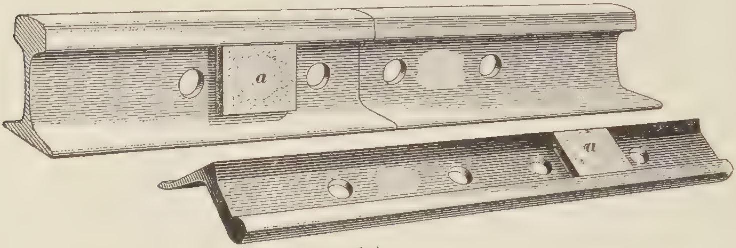


Fig. 22

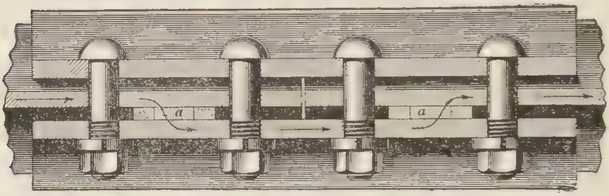
first ground off and both rail and bond treated with Edison-Brown amalgam.

18. Plastic Bond.—Where the fish-plates or channel plates are of large cross-section they can be made to serve as

a bond by providing good contact between the plates and rail. Fig. 23 shows an amalgam bond for this class of work; the plastic amalgam *a* is held in a cork case, which is compressed



(a)



(b)

FIG. 23

when the fish-plates are bolted together, thus bringing the amalgam into intimate contact with the rail and plate surfaces, which have previously been ground off and amalgamated; the path of the current through the joint is indicated in (*b*). In all of these amalgamated bonds a slight movement between bond and rail does not impair the contact; in fact the amalgam acts, to a certain extent, as a lubricant.

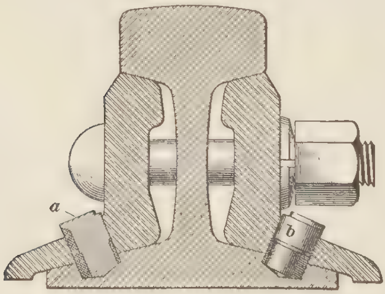


FIG. 24

Fig. 24 shows a method of bonding **T** rails with plastic plug bonds. The fish-plates provide the connection between the abutting rails, and electrical contact is made by means of copper plugs *a*, *b*, **T**-shaped in section, that are well

amalgamated and also dip into amalgam placed in the hole. The plugs are afterwards locked in place by burring over with a hammer and blunt chisel. The lower part of the plug is considerably smaller than the hole, so that a certain amount of relative movement between the angle plate and rail can take place with variations in temperature.

19. Wire Bond With Amalgamated Contacts. Fig. 25 shows three styles of bond, devised by Mr. W. E.

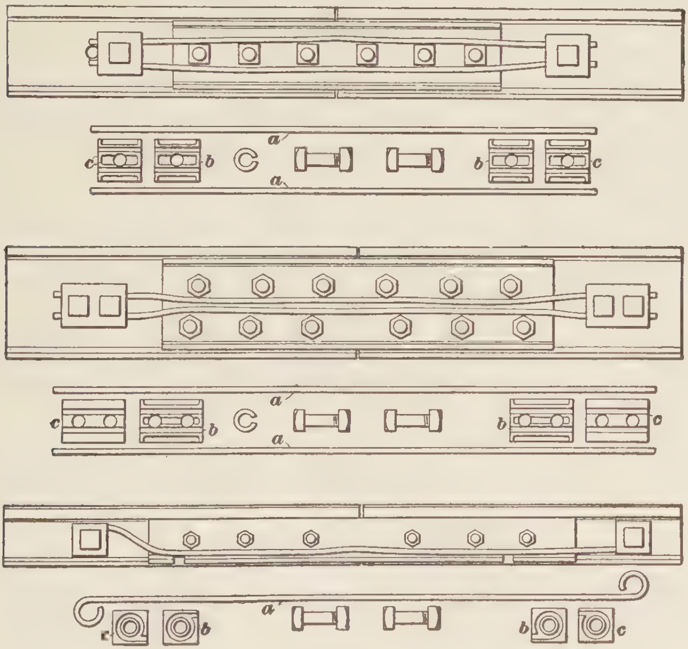


FIG. 25

Harrington, that use ordinary 0000 copper wire for making connection from rail to rail. The wires *a*, *a* are held in contact with the rails by being clamped between two plates *b*, *c* provided with grooves to receive the wires. The contact surface on the web is ground off and covered with plastic amalgam, and an amalgamated cast copper plate is placed against the web of the rail; after the grooves in the casting

and the ends of the wire have been well covered with alloy, a cast-iron plate is placed on top and the whole drawn up tightly by a 1-inch bolt provided with a spring lock washer. Bonds of this type are easily applied; the contacts do not deteriorate, and tests have shown that the resistance across the joint is no greater than that of a corresponding length of rail, provided the bonds are properly proportioned with regard to the rail section.

20. Resistance of Bonds.—In making track joints, the aim should be to keep the electrical resistance at least as low as the resistance of a corresponding length of rail. It is not difficult to do this with a new joint, but the constant jarring and slight movements to which the bonds are subjected will often cause a great increase in resistance. Poor connections from rail to rail are just as detrimental as poor joints in the overhead feeders and much more attention is now paid to efficient rail bonding than formerly.

21. A No. 0000 B. & S. wire has a cross-section of .1662 square inch which, assuming the resistance of steel as 10 times that of copper, is equivalent to 1.662 square inches of steel. A bond 1 foot long connecting two 60-pound rails (6 square inches cross-section) will have a resistance equal to that of $\frac{6}{1.662} = 3.61$ feet of rail, neglecting resistance at the bond contacts. The total resistance of a joint is the resistance of the bond in parallel with the resistance that the joint would have without any bond. The channel plates or fish-plates provide some conductivity, but it is very uncertain owing to the variable nature of the contacts between plates and rail. If the work is done carefully, the resistance as measured across the fish-plates and bond, say 3 feet of rail, can be kept as low as the resistance of 3 feet of solid rail. It is necessary, of course, to proportion the bonding according to the weight of the rail; for example, a 90-pound rail should be bonded heavier than a 60-pound, either by using a heavier bond connection or, preferably, by providing two or more bonds at each joint.

TABLE II

LENGTHS OF RAIL EQUAL IN RESISTANCE TO BOND 1 FOOT LONG

Weight of Rail Pounds per Yard	Cross-Section Square Inches	Equivalent Cross-Section of Copper Square Inches	Feet of Rail Equal in Resistance to Bond 1 Foot Long Assuming Resistance of Steel = 10 × Resistance of Copper							
			Single No. 0000 B. & S.	Two No. 0000 B. & S. in Parallel	Single No. 000 B. & S.	Two No. 000 B. & S. in Parallel	Single No. 00 B. & S.	Two No. 00 B. & S. in Parallel	Single No. 0 B. & S.	Two No. 0 B. & S. in Parallel
40	4	.4	2.41	1.21	3.04	1.52	3.82	1.91	4.82	2.41
45	4.5	.45	2.71	1.36	3.41	1.71	4.31	2.16	5.42	2.71
50	5	.5	3.01	1.51	3.79	1.89	4.78	2.39	6.03	3.02
55	5.5	.55	3.31	1.66	4.17	2.09	5.26	2.63	6.63	3.32
60	6	.6	3.61	1.81	4.55	2.28	5.74	2.87	7.24	3.62
65	6.5	.65	3.91	1.96	4.93	2.47	6.22	3.11	7.84	3.92
70	7	.7	4.21	2.11	5.31	2.66	6.70	3.35	8.44	4.22
75	7.5	.75	4.51	2.26	5.69	2.85	7.18	3.59	9.04	4.52
80	8	.8	4.81	2.41	6.07	3.04	7.65	3.83	9.65	4.83
85	8.5	.85	5.11	2.56	6.45	3.23	8.13	4.07	10.25	5.13
90	9	.9	5.41	2.71	6.82	3.41	8.61	4.31	10.85	5.43
95	9.5	.95	5.71	2.86	7.21	3.61	9.09	4.55	11.46	5.73
100	10	1.00	6.01	3.01	7.59	3.79	9.57	4.79	12.06	6.03
105	10.5	1.05	6.31	3.16	7.96	3.98	10.05	5.03	12.66	6.33
110	11	1.10	6.61	3.31	8.34	4.17	10.52	5.26	13.27	6.64
115	11.5	1.15	6.91	3.46	8.73	4.37	11.01	5.51	13.87	6.94

22. Table II shows the lengths of rail that are equal in resistance to bonds of various sizes 1 foot long. Thus, if a 70-pound rail is bonded with two No. 0000 bonds, each 1 foot long, the resistance of the bonds is equal to that of 2.11 feet of rail, assuming that the resistance between bonds and rail is negligible and that steel has a resistance 10 times that of copper.

23. The cost of bonds for a given piece of track is such a small item, compared with the total cost, that it pays to be liberal when installing them. Table III shows the resistance of a number of types of bond as measured by Mr. W. E. Harrington. These tests show that it is advisable to use amalgam on bond contacts even with those types of bond that were originally designed for use without amalgam.

24. Cross-Bonding.—It is necessary to cross-bond the rails at certain intervals so that a break in one or more joints may not seriously impair the conductivity of the return circuit. For example, consider a single-track road where the two rails are bonded throughout but not connected to each other. If a break occurs at a given joint, the portion beyond the joint is of no use in aiding as a return for the current and an additional load is thrown on the other rail. If, however, the rails are cross-connected at intervals, the current can flow around the break and only a small section of the rail is cut out. On double-track roads all four rails should be connected together. Cross-bonding, with No. 0000 copper, should be provided at least every 500 feet; tinned wire is very commonly used for this purpose. For similar reasons, the current should be carried around all switches, frogs, and special work by means of heavy bond wires (250,000- or 500,000-circular-mil cable). Joints in special work are liable to work loose because of the pounding, and it pays to take extra precautions in the bonding at all such points on the road.

25. Return Feeders.—It is usually necessary to connect the track to the negative bus-bar in the power house by

TABLE III

RESISTANCE OF RAIL BONDS

No.	Kind of Rail	Kind of Bond	Distance Center to Center of Bond Contacts Inches	Length of Bond Inches	Size of Contact	Size of Bond B. & S.	Number of Wires	Resistance Ohms
1	7-inch girder, Pennsylvania Steel Co. Sec. No. 238	Iron channel pin	45	48	$\frac{9}{16}$-in. pin	0	1	.00071
2		Crown	30	36	$\frac{7}{8}$-in. head	0000	1	.000247
3		Crown (amalgamated)	30	36	$\frac{7}{8}$-in. head	0000	1	.000185
4		Columbia	30	36	$\frac{7}{8}$-in. head	0000	1	.000131
5		Columbia (amalgamated)	30	36	$\frac{7}{8}$-in. head	0000	1	.000126
6		Stranded crown	5	7	$\frac{7}{8}$-in. head	0000	1	.0001
7		Plastic socket	$3\frac{1}{2}$					.000093
8		Ajax bond		$8\frac{1}{2}$	$8\frac{1}{2}$-sq. in.	$\frac{1}{4}$-sq. in. section		.000041
9		Solid rail (no joint)	24					.000024
10		Joint only (no bond)	24					.00071
11	60-lb. T	Ajax (double)	30					.00004
12	60-lb. T	Solid rail (no joint)	30					.000035
13	9-in. girder	Ajax	24	$5\frac{3}{4}$	$5\frac{3}{4}$-sq. in.	$\frac{3}{8}$-sq. in. section		.000031
14		Solid rail	24					.00002

means of a number of return feeders; these are very often attached to the rails by bond connections similar to regular rail bonds.

Fig. 26 shows a return feeder attached by means of a cast-iron terminal and plastic bond; terminal *a* holds the cork case against the web, forming a receptacle into which are

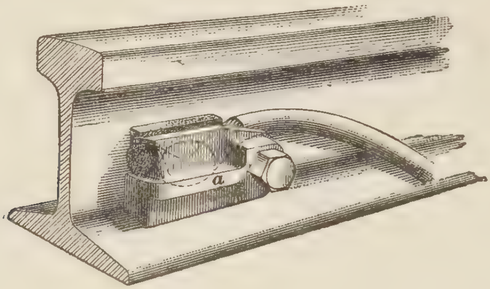


Fig. 26

placed the end of the wire and some of the plastic alloy. The cable end and the spot on the rail are also amalgamated and the casting is bolted to the rail by a $\frac{3}{4}$-inch bolt that is afterwards riveted over to prevent loosening. Similar terminals are used for loops around special work. Fig. 27 shows an electrically welded or brazed feeder cable connection; a copper block *a* about 4 inches square and $1\frac{1}{2}$ inches thick is provided with a groove on one face to take the cable when the block is placed against the rail, as shown. A steel plate *b* is placed over the block, and the cable and blocks brazed to the rail by means of the electric welder. Hard spelter is used, and by this means a 500,000-circular-mil cable can be attached to the rail so that the carrying capacity at the contact is fully as good as that of the cable.

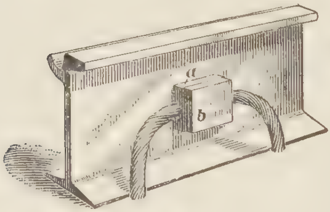


Fig. 27

At one time, it was customary to run a ground conductor parallel to the rails and tap it to them at frequent intervals in order to improve the conductivity of the return circuit. If

the rails are properly bonded so as to take full advantage of their conductivity there is no need of such an auxiliary wire and its use has been practically abandoned; the money may be used to better advantage in improving the rail bonding.

BOND TESTING

26. No matter how well a track may be bonded, tests should be made frequently to see that the bonds are in good condition. This is especially necessary around railroad crossings, special work, or wherever low joints are noticed. It is not necessary to measure the actual resistance of each joint; comparative readings are all that is required. For a given class of bonding, the resistance of a joint in good condition as compared with a certain length of rail is known, and it is only necessary to measure the resistance of the joint in terms of rail length; any joints showing an abnormally high resistance can then be investigated. Usually 3 feet of rail is taken as the standard and the resistance, measured between two points 18 inches on either side of the joint, is compared with that of 3 feet of rail. For example, the bonding may be such that a joint in good condition has a resistance perhaps slightly over that of 3 feet of rail, and if a test showed that the resistance were over twice that of the standard rail length, the bonding would be considered poor.

27. Drop-of-Potential Test.—The simplest method of testing for poor bonds is by measuring the drop across the joint by means of a millivoltmeter and comparing this with the drop across 3 feet of rail. Fig. 28 shows a method of doing this very rapidly and accurately by means of a test car especially fitted up for the purpose. A wooden beam *a* is suspended underneath the rear car platform so that it will be a few inches above the rail. A spring is arranged to press down on the beam and means are also provided for raising it when not in use. To the under side of the beam are attached two stiff copper brushes *b*, *b'*; these are made of several leaves of sheet copper and are set on a slant, as shown, so that they will slide easily along the rail and make

a good running contact. They should have at least 1 square inch contact surface with the rail; high-contact resistance will have a marked effect on the accuracy of the millivoltmeter readings. A resistance *c* is carried on the car so that a large steady current can be made to flow through the track; resistance wire wound on a frame and submerged in a barrel of water is capable of carrying a large current and furnishes a resistance that is fairly constant.

In making bond tests, it is best to pass sufficient current through the joints to give good readable deflections on the millivoltmeter and the current used to propel the test car, or that taken by other cars on the line, is not usually large

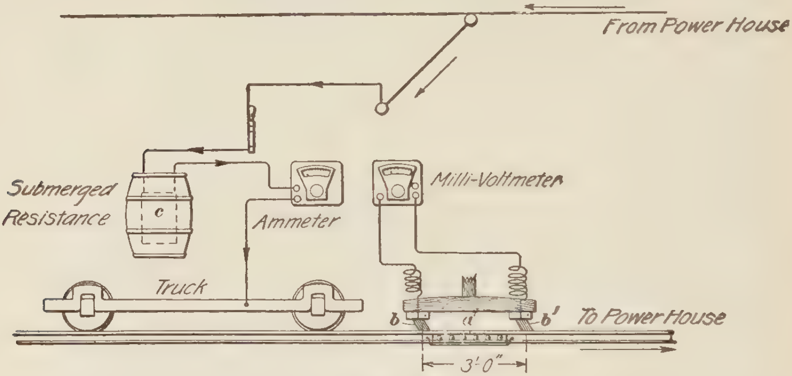


Fig. 28

enough or steady enough for the purpose. The current flows from the trolley, through the resistance and ammeter to the truck and rails, and thence back through the track to the power house. The brushes *b*, *b'* are placed 3 feet apart, and as the car moves slowly over the track the brushes span the joints in succession. A millivoltmeter is connected to the brushes, and when the brushes are as shown in Fig. 28 it indicates the drop across the joint. When the brushes are not on a joint, the voltmeter reading is the drop across 3 feet of solid rail. Since the current in the rail is the same as that in the joint, the voltmeter readings are proportional to the resistances of 3 feet of rail and 3 feet including the joint. The car can also be fitted with another set of brushes

over the other rail, this set being connected to a second voltmeter; tests of the bonds on both sides of the track can thus be made at the same time. The rheostat is adjusted so that a normal joint will give a good readable deflection and the car is then run slowly over the line, any joints that give abnormally high readings can thus be quickly located, marked by ejecting whitewash on the track, and afterwards examined.

FIG. 29

The test should preferably be carried out at some time when traffic is light so as not to interfere with the regular operation of the cars.

28. Conant Bond Tester.—The method of testing devised by Mr. R. W. Conant, while it is not as rapid as the one just described, is very useful where a moderate number of joints are to be gone over. Fig. 29 shows the method of using the instrument. A **T**-shaped pole is provided with three hardened-steel knife-edge contacts *a*, *b*, *c*, and

when the pole is placed on the rail as shown, contacts *b*, *c* span the rail joint and *a*, *b* span 3 feet of solid rail, plate *p* being placed over the joint. The pole is made of tough wood that has considerable spring to it and when the two end contacts rest on the rail, the center contact is 1 or 2 inches above the rail and is pressed down by placing a foot on the pole, as shown; this forces the end contacts out sidewise slightly and the hardened chisel-like contacts cut through any scale or dirt that may be on the rail, thus making a good connection. In order to make sure that the contact is good, the center pole can be moved back and forth, as indicated by the dotted lines; the contacts must be sharpened occasionally by means of a small oilstone.

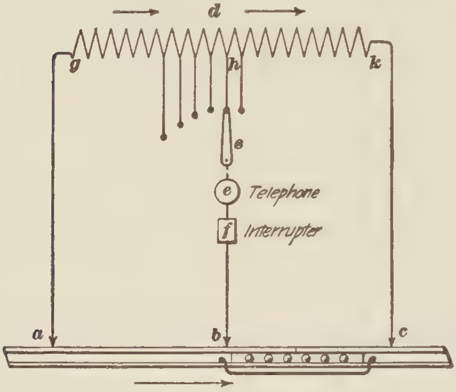


FIG. 30

29. The operation of the instrument will be understood from Fig. 30, where *a*, *b*, *c* represent the three contacts on the rail; *d* is a resistance to which the central contact can be connected at various points by means of a multipoint switch *s*. In series with the middle wire is included a telephone receiver *e* and an interrupter *f* consisting of a clockwork mechanism that drives a toothed contact wheel on which presses a small contact spring. The instrument works on the principle of a Wheatstone bridge and is operated by current obtained from the rail.

Assume that the rail current is represented by the heavy arrow; it will be the same in the section of rail *a b* and in the joint *b c* and will fluctuate according to the number of cars in operation beyond the joint. Resistance *d* being shunted across the rail and joint, part of the current will

flow as shown by the small arrows. If the rail section *a b* is equal in resistance to the joint *b c* and if switch *s* is so placed that resistance *g h* is equal to *h k*, there will be no current in the middle wire and no sound in the telephone because points *h* and *b* will be at the same potential. If the joint has a greater resistance than the rail section, a balance can be obtained by moving the switch to the left, thus virtually shifting point *h* along the resistance until the drops through the two resistance sections become equal to the drops through the corresponding rail sections. It is hardly possible to obtain such an exact balance that there will be no sound whatever in the telephone, but the point where the sound is a minimum can be quickly located. The interrupter is used to make a clicking sound in the telephone; fluctuations in the railway current would not in themselves be regular enough to give an easily detected sound.

The contacts of switch *s* are numbered so as to read off the resistance of the joint in terms of 3-foot length of rail. Thus, if a balance is obtained with the switch on point 1 it indicates that the joint has a resistance equal to 3 feet of rail. If a balance is obtained on 1.5, the joint resistance is equal to 1.5 × 3 or 4.5 feet of rail; if a balance is obtained on 2, the joint resistance is equal to 6 feet of rail. Readings from 1 to 2 are considered as indicating good bonding; readings on points 3 or 4 indicate poor bonding; all readings above 4 indicate bad bonding. For any given class of bonding, the point at which the switch should give a balance for a good joint is known, and bad joints can be easily located. Good bonding will never have a resistance greater than twice the same length of rail, and in the better class of work it will not exceed 1 to 1.5 times an equal length of rail; in fact, if proper care is taken there is no reason why the joint resistance should not be less than that of a 3-foot rail length, particularly if solid rail joints are used.

30. Table IV shows the results of some tests on different bonds made by the method shown in Fig. 28.* They were

* W. E. Harrington, Journal of the Franklin Institute, Vol. CLVII.

TABLE IV

RESULTS OF RAIL-BOND TESTS

No.	Trade Name of Bond	Trade Name of Rail Section	Line Voltage	Amperes Used	Drop Across 3-Foot Section of Rail (Millivolts)	Drop Across 3-Foot Section Including Bond (Millivolts)	Ratio Resistance of Bond to Rail	Date Placed	Style of Joint
1	C. & S. No. 1 (See Fig. 25)	9-inch girder Pennsylvania Steel Co. Sec. 200	550	200	28	12	.43	1899	Regulation fish-plate
2	C. & S. No. 2 (See Fig. 25)	9-inch girder Pennsylvania Steel Co. Sec. 200	545	220	27	15	.55	1900	Regulation fish-plate
3	C. & S. No. 3 (See Fig. 25)	4½-inch **T** Pennsylvania Steel Co. Sec. 237	540	150	30	12	.40	1901	Regulation fish-plate
4	Bryan	7-inch girder Pennsylvania Steel Co. Sec. 238	550	200	25	14	.55	1900	Regulation fish-plate
5	Flexible plug	4½-inch Wharton	425	140	40	80	2.00	1900	Regulation fish-plate
6	Crown plug	6-inch Wharton	430	150	24	75	3.12	1896	Regulation fish-plate
7	Trenton plug	6-inch Wharton	430	155	25	78	3.12	1898	Regulation fish-plate
8	Cast weld	9-inch girder Pennsylvania Steel Co. Sec. 200	555	200	28	12	.43	1898	Cast weld Wharton
9	Plastic Edison-Brown	9-inch girder Pennsylvania Steel Co. Sec. 200	550	200	27	18	.66	1896	Regulation fish-plate
10	Flexible **U** bond	7-inch girder	460	180	28	35	1.25	1899	Regulation fish-plate
11	Ajax	9-inch girder Pennsylvania Steel Co. Sec. 200	560	16c	29	26	.90	1900	Regulation fish-plate

made in September, 1903, so that the bonds had been in use for periods ranging from 2 to 7 years.

31. Testing Resistance of Track-Return Circuit. After a road has been in operation some time, it is often found that the drop on certain sections is larger than it should be and the question naturally arises as to whether the track return is at fault or whether more copper is required in the overhead feeders. To find this out, it is necessary to know the comparative resistances of the two; if the track resistance is high compared with that of the overhead line, additional return feeders should be run and vice versa.

Fig. 31 shows one method of measuring the resistance of a railway circuit; FF is the feeder running out to the section under consideration and RR the rail return. A time

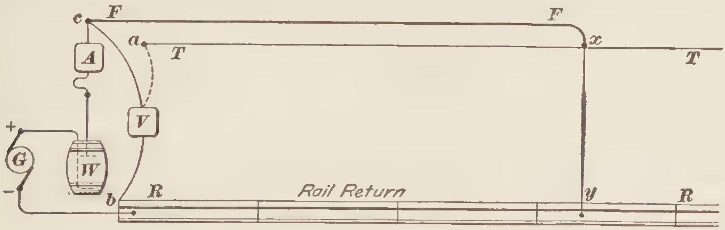


FIG. 31

is selected at night, when traffic can be kept off the section for a short time, and a water rheostat W is connected in series with the feeder F and the regular feeder ammeter A. The feeding-in point x is connected to the track as shown at xy, and a steady current sent through the circuit $G+-W-A-c-F-F-x-y-R-G-$. The drop through the entire feeder and rail circuit is measured by a voltmeter V connected to c and b. From the readings of A and V, the total resistance of the feeder and rail circuit is at once determined. The resistance of the feeder FF can be calculated from its known length and cross-section, and its resistance subtracted from the total resistance of the circuit will give the resistance of the track return.

The above method of finding the resistance of the track return assumes that there are no bad joints or unusually poor conductivity in any part of the feeder FF, but such is not always the case. If the trolley wire runs back to the power house or if there is another feeder near by that can be used as a pressure wire, the drops in the feeder and track can be measured separately and an accurate idea gained as to just how the drop is distributed. For example, if the upper voltmeter terminal is connected to the end a of the trolley wire instead of to c, the reading obtained will be the drop through the track alone, because the voltmeter takes such a small current that there will be practically no drop through Tx. If one terminal of the voltmeter is connected to c and the other to a, the reading obtained will be the drop in the feeder FF. This method is the one to be preferred, because it at once gives an accurate comparison between the loss in the overhead work and the loss in the track and shows what part of the system requires attention in order to bring about better working conditions.

TRACK CONSTRUCTION

GENERAL FEATURES

32. The kind of track construction to be used for a given road will depend largely on where the road is located. and the allowable cost. If the soil has a very poor bottom, the subwork of the roadbed must be much more substantial than where the soil is firm or where there is a rock bottom. Again, in some places provision must be made for draining the roadbed.

33. Ties.—The woods most commonly used for **ties** are white oak, red oak, cedar, chestnut, yellow pine, hemlock, and spruce; oak is used more than any of the others. Ties for a standard gauge (4 feet $8\frac{1}{2}$ inches) road are usually 6 in. × 8 in. × 8 ft. and are spaced from 2 to $2\frac{1}{2}$ feet between

centers. In some classes of trackwork in paved streets, where the tracks are largely supported by concrete, the spacing of the ties may be much wider than that required for an open track; in fact, in certain classes of construction, ties are dispensed with altogether, the rails being held to gauge by means of tie-rods spaced about 10 feet apart.

The life of a tie depends much on climatic conditions and the material in which it is bedded. Under ordinary conditions, sound oak, cedar, or chestnut ties should last from 8 to 10 years, while pine, hemlock, and spruce will last from 4 to 6 years. Ties, when completely covered, deteriorate much more rapidly than when partly exposed; when they are raised on stone ballast, the drainage is much more perfect than when buried in earth, and the life is much longer.

34. Arrangement of Joints.—In placing the rails, opinion is divided as to how the joints should be disposed; some engineers prefer putting the joints opposite each other, while others advocate staggering them, i. e., making the joint in one rail come in line with the center of the opposite rail. It has been the general custom in America to stagger the joints, but the use of opposite joints is now becoming more common, as many engineers are strongly of the opinion that they are much to be preferred to staggered joints. When staggered joints are in bad condition, the car acquires a disagreeable side-rolling motion very much like that due to a sprung axle. The car is thrown from one side of the track to the other and the part of the rail opposite a joint becomes worn unevenly, thus making the side motion still worse, with the result that the track is thrown out of alinement. With opposite joints, the worst that can happen is an up-and-down motion, which will jolt the car, but will not cause the severe side thrusts that are always found with defective staggered joints.

35. Methods of Installing Electric Roadbeds.—On interurban electric roads, steam construction can be followed closely. It frequently happens, however, that electric roads

are run in streets that, if not already paved, will be at some future time, and hence the conditions are somewhat changed. The methods of building electric roads differ so radically that it can be truly said that the only elements of construction in common to all electric roads are the earth and the rails. Some roads have wooden cross-ties, some metal, and others have no cross-ties at all. One road must build an expensive substructure for its roadbed and another, on account of natural conditions, may have to lay scarcely any roadbed. There can be no better way of bringing out these several points in construction than to take examples of roads on which they occur.

TYPICAL ROADBEDS

INTERURBAN ROADS

36. The permanent character of the track as a whole depends greatly on the character of the roadbed; if, after the substructure is laid, the roadbed gives or swerves in places, everything that rests on it gives and swerves also, so that in course of time the surface of the track becomes undulating and serpentine in outline. Electric interurban roads, as far as possible, now follow steam-road practice in their roadbed and trackwork, and for out-of-town work they could not do better.

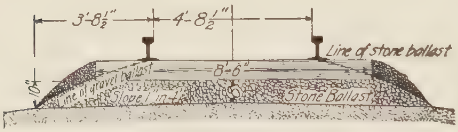


FIG. 32

Fig. 32 shows a standard steam-road construction; other examples of track construction for cross-country roads have already been shown in connection with line work. The same care and exactness that are observed in steam-road construction should be observed in electric railroading, where the train speeds are often almost as high and other conditions just as severe.

CITY ROADS

37. Fig. 33 shows a cross-section of a substantial road-bed in the State of New York. The figure shows a single track only, although the road is double track. A trench 23 inches deep is opened up 18 feet wide and is well rolled and

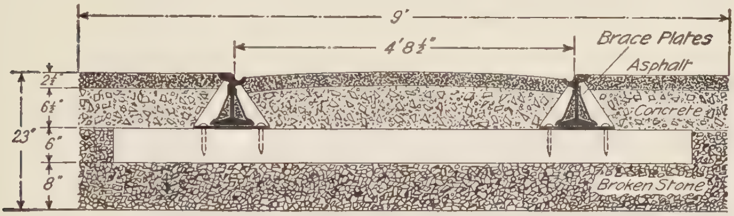


FIG. 33

filled to a depth of 8 inches with 2-inch broken stone, soft spots in the rolled surface being dug out and also filled with stone or other solid material. The stone is rolled until it is firm at a depth of 8 inches. On this ballast are laid the ties. 6 in. × 7 in. × 7 ft. 6 in., a little less than 2 feet between centers, except at the joints, which are supported by three ties about 15 inches between centers; 60-foot rails are then laid on the ties, ends butted and joints staggered; before jointing, the ends of the rails and the joint plates are well cleaned to take the bonds. The rails are then coupled, the plates bolted tight, brace plates installed every 3 or 4 feet, ties lined up and spiked to the rail. The track is then lined and surfaced and the space between the ties filled with broken stone, well tamped to the top of the tie. The rail is then finally

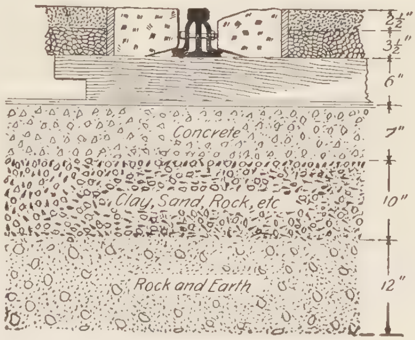


FIG. 34

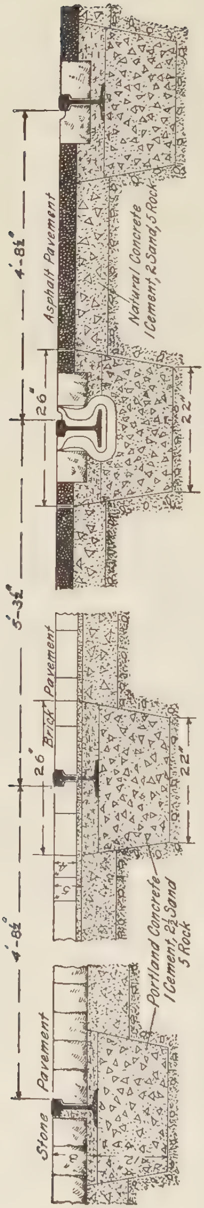

Asphalt Pavement
4'-8½"
Natural Concrete
1 Cement, 2 Sand, 5 Rock
26"
22"
5'-3½"
Brick Pavement
26"
22"
Portland Concrete
1 Cement, 2½ Sand
5 Rock
4'-8½"
Stone Pavement

FIG. 35

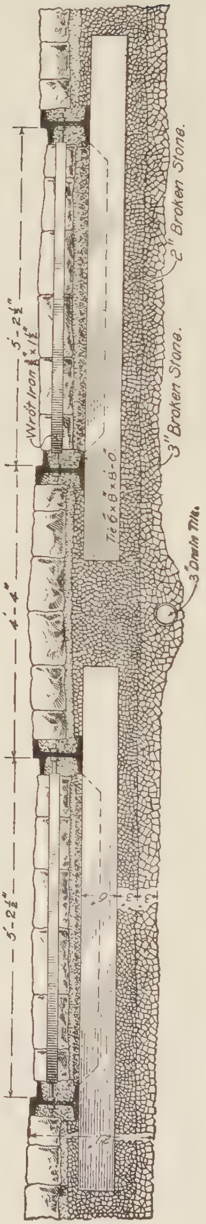

2" Broken Stone.
5'-2½"
Wrot Iron ⅜×1½"
Tie 6"×8"×8'-0"
3" Broken Stone.
3" Drain Tile.
4'-4"
5'-2½"

FIG. 36

lined, the joints secured, and the broken stone or concrete brought up to the paving.

38. Fig. 34 is an example of a roadbed construction on a weak subsoil. A trench 36 inches deep and the width of the tracks is dug and, as shown by the figure, it is filled to a depth of 29 inches with successive layers of 12 inches of hard earth and rock well beaten down; 10 inches of earth, pebbles, clay, sand, and rocks, well tamped; 7 inches of new concrete; and $6'' \times 8'' \times 8'$ hard pine ties, previously boiled in asphalt, are laid on the concrete to take 80-pound **T** rails.

39. Fig. 35 shows the construction used by the Twin City Rapid Transit Company, operating in St. Paul and Minneapolis, for tracks with stone, brick, or asphalt pavement. The rails rest on longitudinal concrete beams tied together by a bed of concrete. Cast welded joints 16 inches long and weighing 190 pounds are used. The cast joint is especially shaped so as to interfere as little as possible with the paving. The rails are 8-inch shanghai **T** type, weigh 79 pounds per yard, and are in 60-foot lengths.

40. Fig. 36 shows a construction used for double-track work with stone pavement in Pittsburg. The rail is 90-pound girder in 60-foot lengths. The foundation is of broken stone, and drainage is provided by 3-inch drain tiles placed between the tracks, as shown. The gauge of the track is, in this case, 6 inches wider than standard, being 5 feet $2\frac{1}{2}$ inches.

41. Fig. 37 shows a very heavy track construction with concrete, used in Philadelphia. The track is supported on cast-iron chairs provided with screws for adjusting and holding the track to gauge. The chairs are spaced 5 feet apart and are bedded in concrete, as shown; a solid sheet of concrete $4\frac{1}{2}$ inches thick, together with tie-rods at regular intervals, prevent any spreading of the concrete stringers on which the rails are carried.

42. Fig. 38 shows a section of track construction in Detroit that combines the concrete-beam feature and the steel

cross-tie (3-inch angle bars) used more as a tie-rod for keeping the rails to gauge than as a solid resting place for the rails. The concrete-beam work ordinarily goes to a depth of only 6 inches, but in soft spots it may be as deep as 2 feet.

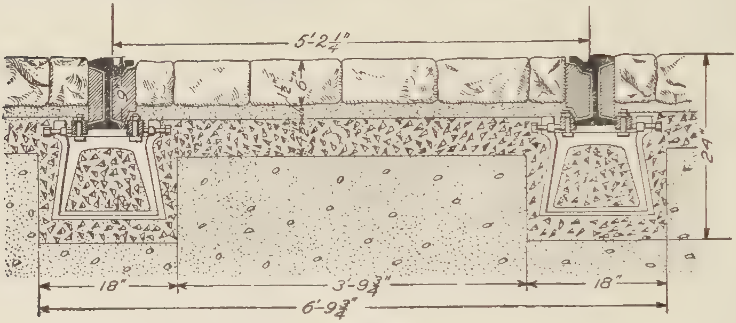


FIG. 37

43. Fig. 39 shows a construction adopted in New Orleans where the subsoil is very soft and yielding. Several of the

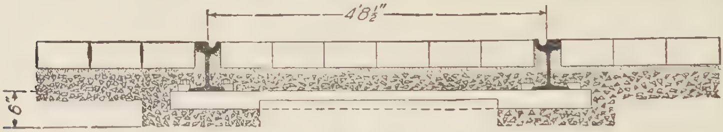


FIG. 38

long lines in the city are built on neutral ground between two driveways, so that they are not subjected to the wear

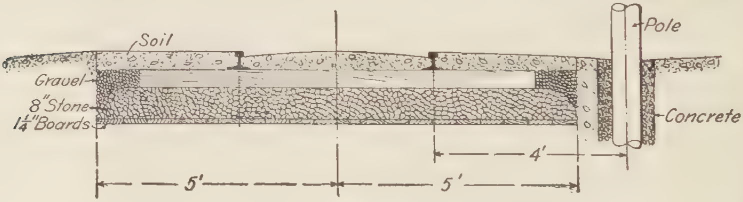


FIG. 39

and tear of wagon traffic. This location of the track admits of the use of a **T** rail as shown in Fig. 39. The first step is to dig two trenches, one for each track, about 2 feet deep and 10 feet wide. On the bottoms of the leveled trenches

are laid lengthwise $1\frac{1}{4}$-inch yellow-pine boards; these act as the foundation for a layer of $1\frac{1}{2}$-inch broken stone, on which the $6'' \times 8'' \times 8'$ creosoted yellow-pine ties rest, 2 feet between centers. The space between the ties is filled partly with broken stone and partly with gravel that goes to the top of the ties. On top of the gravel is put a layer of soil in which grass is sown, so that a few months after the work is done the whole neutral ground is grass-grown—a feature that almost does away entirely with the clouds of dust ordinarily raised by a car in course of rapid transit. The plank construction on the bottom of the roadbed prevents the tendency of the track to sink into the soil and cause undulations in the surface line of the rail.

44. Use of Plank to Secure Even Pavement.—In some classes of track construction, where there is very little space between the upper surface of the ties and the under side of the pavement in which to place a solid foundation for the pavement, an uneven road surface is almost sure to result because of settlement between the ties. The roadbed should be designed so that the pavement will have an even and secure foundation, but in cases where this is not possible it has been found advantageous to lay the pavement on rough hemlock planks that have been placed on the ties; a thin bedding of sand is placed beneath the pavement. The planking affords an even support but, like the ties, it has to be renewed in course of time.

THIRD-RAIL ROADS

45. Form of Third Rail.—In practically all the third-rail roads so far installed, the conductor rail has been of the ordinary **T** section. Other sections have been proposed, one of which, suggested by Mr. W. B. Potter, is shown in Fig. 40. It is not necessary to have the same degree of stiffness in a conductor rail that is required in a track rail, and the plain rectangular section shown in Fig. 40 was designed with the idea of making the rail as easy to roll as possible; also, to provide a simple means of clamping the rails at joints without

drilling holes through them. A rail of this section weighs about 98 pounds per yard. So far, however, special shapes have not been introduced to any extent, as the standard **T** sections are more easily obtained.

46. Location of Third Rail.—The third rail may be located on either side of the track, as may be most convenient; on double-track roads, the two third rails are usually placed between the tracks. At different points on a road, it may be found advisable to change the location of the rail from one side to the other, but as both sides of the cars are equipped with collecting shoes, this makes no difference so far as the collection of current is concerned. The relation of the third rail to the track rails varies on different roads and is determined largely by the clearance that must be allowed for locomotives or rolling stock that may be run over the road. Where steam locomotives are run over a third-rail road, the conductor rail must be located so as not to interfere with the locomotive cylinders, which usually project farther than any other part.

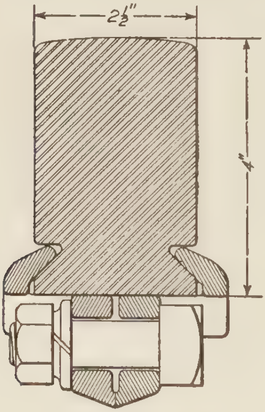


FIG. 40

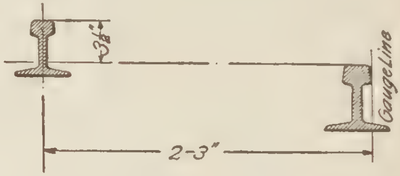


FIG. 41

Fig. 41 shows the location recommended by a committee of the Master Car Builders' Association. The center of the third rail is 2 feet 3 inches from the gauge line of the nearer track rail and the tread of the third rail is 3½ inches above that of the track rail. The size of the third rail for a given road is determined, to a certain extent, by the amount of current required for the cars. Weights less than 60 pounds per yard are seldom used, unless the traffic is light, and very often the rail is of the same weight as the track rails;

60-foot rails are desirable because of the decreased number of joints.

47. Protection of Third Rail.—On many roads, the third rail is not protected in any way, but there is a growing demand for protection of some kind that will make it difficult for accidental contact to be established between the third rail and ground or track rails. Also, protection is desirable to prevent the accumulation of ice or snow on the rail. Fig. 42 shows a simple method of protection as used on a number of elevated roads. Planks are run parallel to the rail and project about 2 inches above the head; anything accidentally dropped across the rail is prevented from making contact by the projecting planks. This

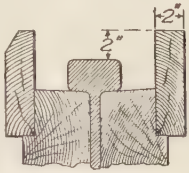


FIG. 42

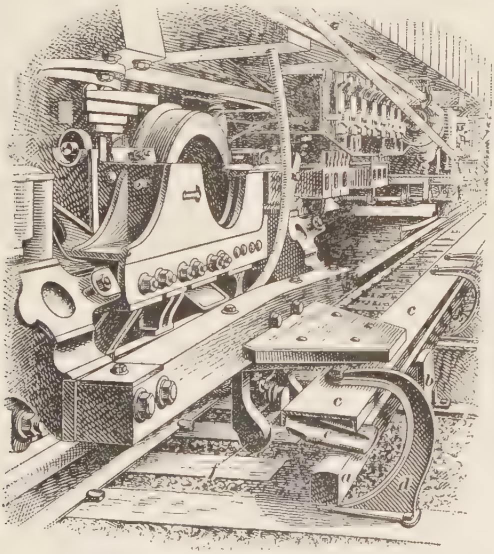


FIG. 43

method does not protect the rail from snow or sleet, nor does it afford as great a measure of safety as the plan shown in Figs. 43 and 44, which represents a protected third rail used by the General Electric Company.

Fig. 43 shows the general arrangement of the third rail and collecting shoe with reference to the motor truck, and Fig. 44 shows the details. The conductor rail *a* is supported on reconstructed granite insulators *b* and is covered by a

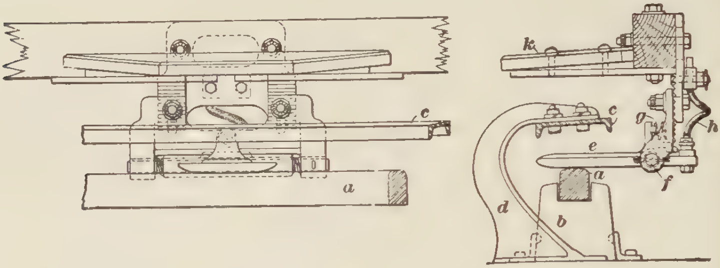


Fig. 44

channel iron *c* fastened to brackets *d* that rest on ties projecting about 18 inches beyond the regular ties. The shoe *e* is in the form of a flat plate hinged at *f* and held in contact with the rail by the spring *g*; flexible cable *h* connects the

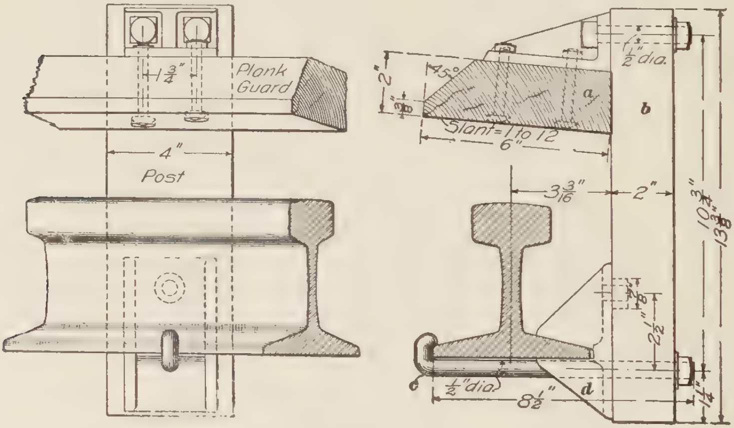


Fig. 45

shoe to the main trunk wire running to the controlling apparatus. A projecting wooden guard *k* prevents accidental contact with the parts of the shoe. With this construction, it is almost impossible for any one to step on the third rail

or for pieces of metal to drop across it and the track rails, thereby causing a short circuit.

48. A modification of the method just described is shown in Fig. 45, which represents the method of rail protection used on the Wilkes-Barre and Hazleton road; a very similar method is used on the New York subway, and in both cases the style of shoe shown in Fig. 44 is employed. The guard consists of a 2-inch pine plank *a* fastened to 2″ × 4″ oak posts *b*, as shown. The posts are supported from the foot of the rail by clamping them by means of a special bolt *c* and a bearing casting *d*, formed to fit the foot of the rail. The construction as a whole is much cheaper than that shown in Fig. 43 and affords equally good protection. Fig. 46 shows the arrangement of the third-rail guard used on the New York subway.

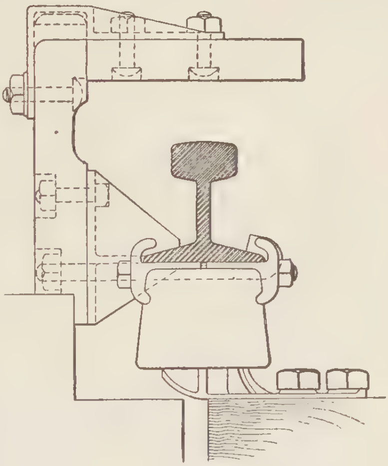


FIG. 46

49. Arrangement of Third Rail at Highway Crossings.—Where a third-rail road crosses a public highway, it is necessary to break the contact rail and make connection by means of a cable carried across either overhead or underground. The connection is nearly always made by means of underground cable, which is much shorter than an overhead one could possibly be. Fig. 47 shows a typical crossing. The contact rail *a* is provided with cast-steel, inclined, approach blocks *b*, *b* that allow the shoes to glide on to the rails without shock. At *c*, a cable is attached to the rail and is carried underground to *d*, where it connects to the rail again, thus preserving the continuity of the conducting system; the cable should have a cross-section equivalent, in carrying capacity, to that of the rail;

1,000,000-circular-mil, lead-covered, paper-insulated cable is often used for this purpose.

Various methods are used for running the cable; one very common plan is to incase it in tile and fill the tile, at the ends, with insulating compound that will prevent water from entering. The cable must be thoroughly insulated from the ground, otherwise there will be leakage and consequent electrolytic action that will eat away the cable in course of time. Fig. 48 shows a method used on a third-rail road in

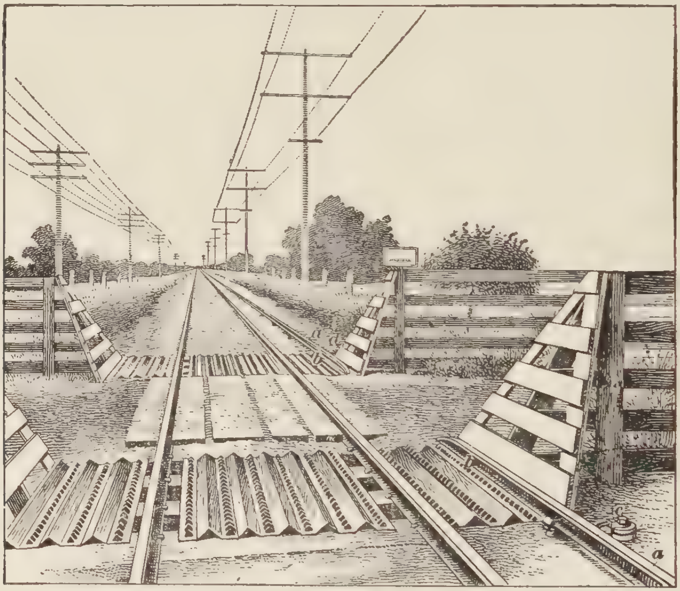
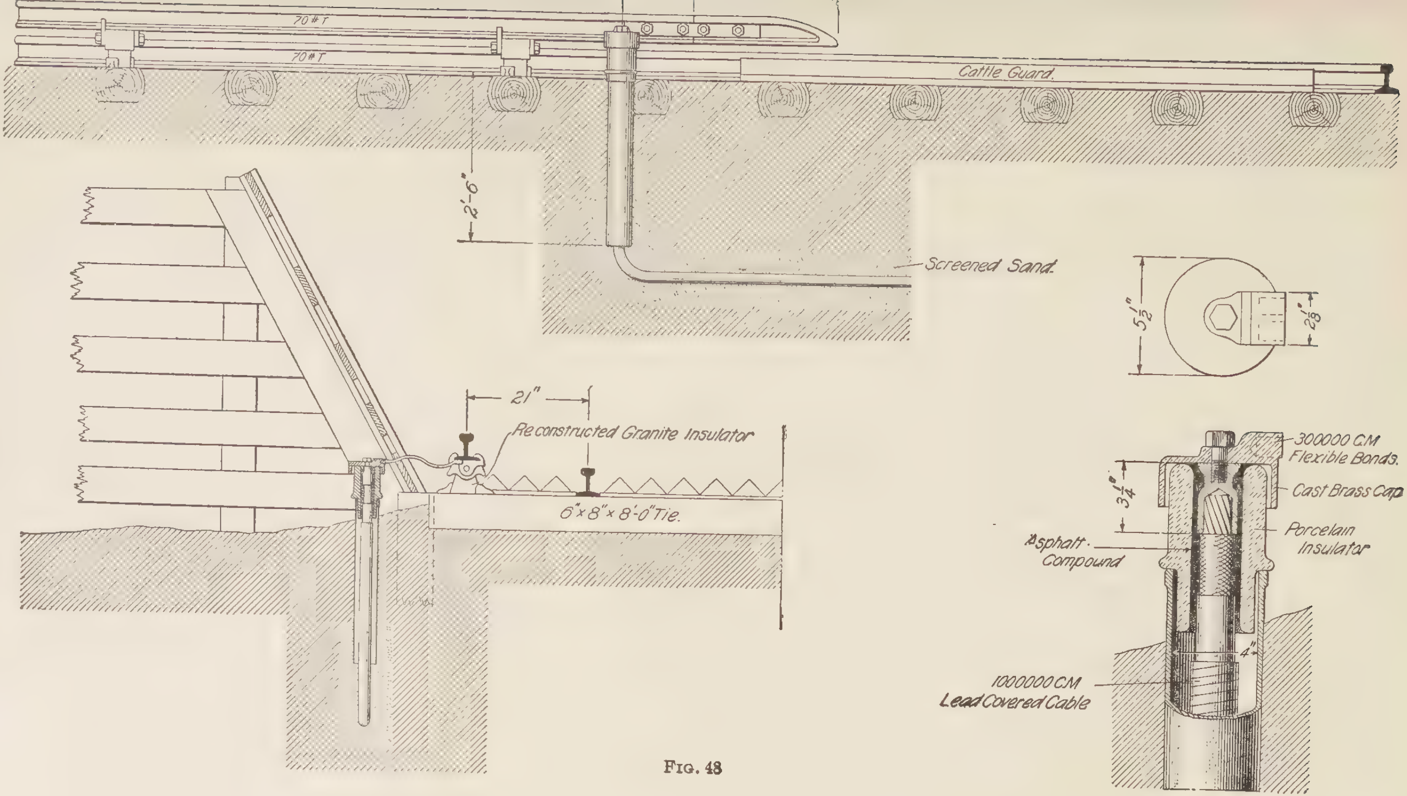


FIG. 47

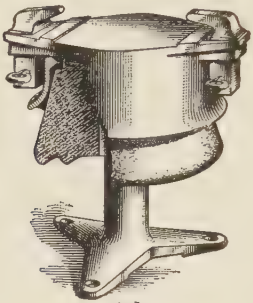
Michigan, where the cable is carried through a heavy porcelain insulator set in a cast-iron pipe. The strands of the cable are soldered into a terminal casting and after the lower part of the insulator has been plugged with oakum the space is filled with insulating compound that prevents moisture from entering the paper insulation of the cable, which, in this case, has a lead sheath covered with jute treated with asphalt. A brass cap is bolted to the cable terminal and from it two 300,000-circular-mil flexible bonds connect to the



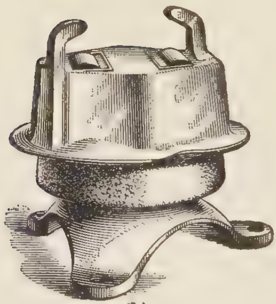
70#T
70#T
Cattle Guard.
2'-6"
Screened Sand.
5 1/2"
2 1/8"
21"
Reconstructed Granite Insulator
6"x8"x8'-0"Tie.
300000 C.M
Flexible Bonds.
3 1/4"
Cast Brass Cap
Porcelain
Insulator
Asphalt.
Compound
4"
1000000 C.M
Lead Covered Cable

Fig. 48

rail. The cable is bedded in screened sand after it leaves the pipe; with this construction there is little danger of electrolytic action on the cable sheath.



(a)



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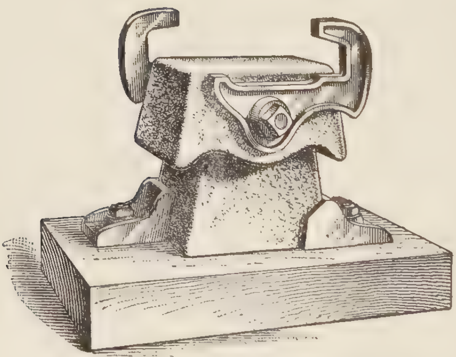


(c)

Fig. 49

50. Third-Rail Insulators.—The third rail should be thoroughly insulated from the track rails and ground by being mounted on suitable insulators that are strong mechanically and allow the conductor rail freedom for expansion and contraction. They have, in many cases, been made of specially treated wood provided with an iron cap for the rail to rest on, but in the best construction special insulating material, such as reconstructed granite, is used. Fig. 49 shows three common types of insulator in which the insulating material is of reconstructed granite. In (*a*) and (*b*), the rail rests on an iron cap and is prevented from moving sidewise by means of lugs; in (*c*), the rail rests on

the granite block and is restrained sidewise by special castings held by a bolt passing through the molded granite. All fastenings should allow a certain amount of up-and-down play; the weight of the rail is amply sufficient to hold it in place, and if it is too tightly fastened undue strains will be thrown on the insulators. Insulators are usually placed on every fifth tie, which is made about 2 feet longer than the others.

51. Third-Rail Leakage.—Tests have shown that the current leakage per mile of third rail is very small if proper precautions are taken; very often the leakage from a poorly insulated underground cable at a road crossing will amount to more than that from several miles of third rail. Tests by Mr. R. P. Leavitt,* on the Albany and Hudson road, on a section of third rail entirely disconnected from all cables at crossings, showed a leakage varying from .057 ampere per mile, after a rain lasting 20 hours, to .023 ampere per mile in hard freezing weather with light snow on track. Tests made on the whole road, including cables at crossings, showed an average leakage of about .5 ampere per mile and investigation showed that the greater part of the leakage was due to defective insulation of crossing cables. The insulators were of specially prepared wood with an iron cap.

52. Sleet Cutters for Third Rail.—Where the head of the third rail is not protected from rain or snow, as, for example, with the ordinary unprotected rail or with the arrangement shown in Fig. 42, considerable trouble is caused by the accumulation of snow and ice. A rain followed by freezing forms a thin film of ice on the rail, which is very difficult to remove and is a non-conductor of electricity. When third-rail roads were first operated on a large scale, numerous tie-ups resulted from this cause, but experience has shown that the sleet can be removed by suitable appliances. In some cases, brine is sprinkled on the third rail from a tank carried on a car, but a better method is to use

*Street Railway Journal, Vol. XXI, No. 16.

some form of sleet cutter. Fig. 50 shows the sleet-cutting device used on the Manhattan Elevated Railway, New York. It is fastened to an extension of the beam that supports the collecting shoe so that the cutter, or scraper, is directly in advance of the shoe. The cutter consists of a number of steel plates *a* cast into a block *b*, the plates being set at an

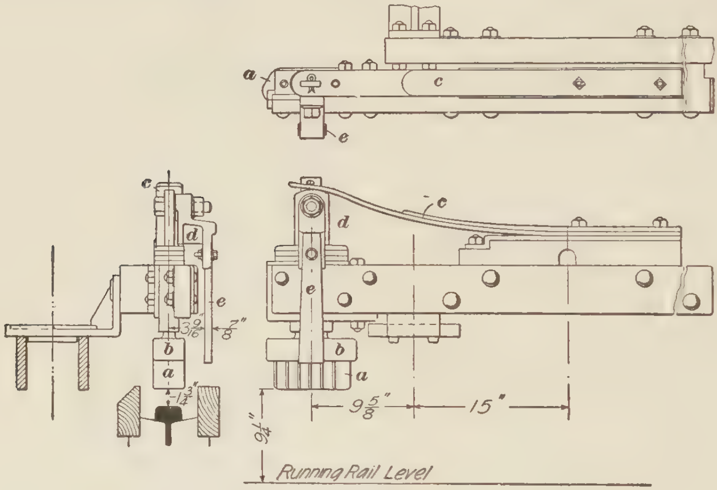


FIG. 50

angle so that they will slide over any slight projections at the rail joints. The cutter is pressed against the rail by a flat spring *c*, and a cam *d* operated by lever *e* is arranged to hold the shoe up when it is not in use. By moving lever *e* to one side, the shoe can be lowered by the motorman or it can be operated by a tripping device controlled from a central point.

53. Fig. 51 shows a style of contact shoe and sleet brush used on the Brooklyn elevated road. The shoe *a* is of the ordinary link type and is suspended from a steel casting *b*, which also forms one of the terminals for the shoe fuse *c*. The other terminal *d* of the fuse is insulated from casting *b*, and to it is attached the cable *e* leading to the controlling devices. The sleet cutter consists of a stiff brush *f* made of

steel ribbon $\frac{1}{8}$ inch wide, No. 23 B. & S. thick, set in a hard maple block. The brush is insulated from its guide bar and is pressed against the rail by spring *g* with a pressure of about 75 pounds. When not in use, the brushes are raised from the rail and held up by throwing handle *h*.

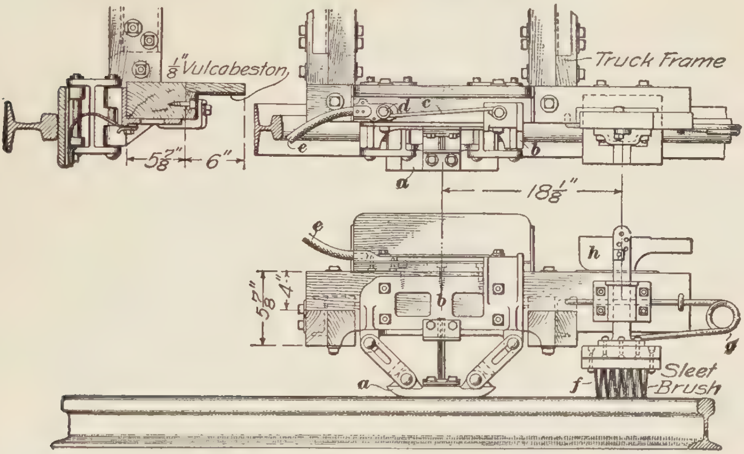
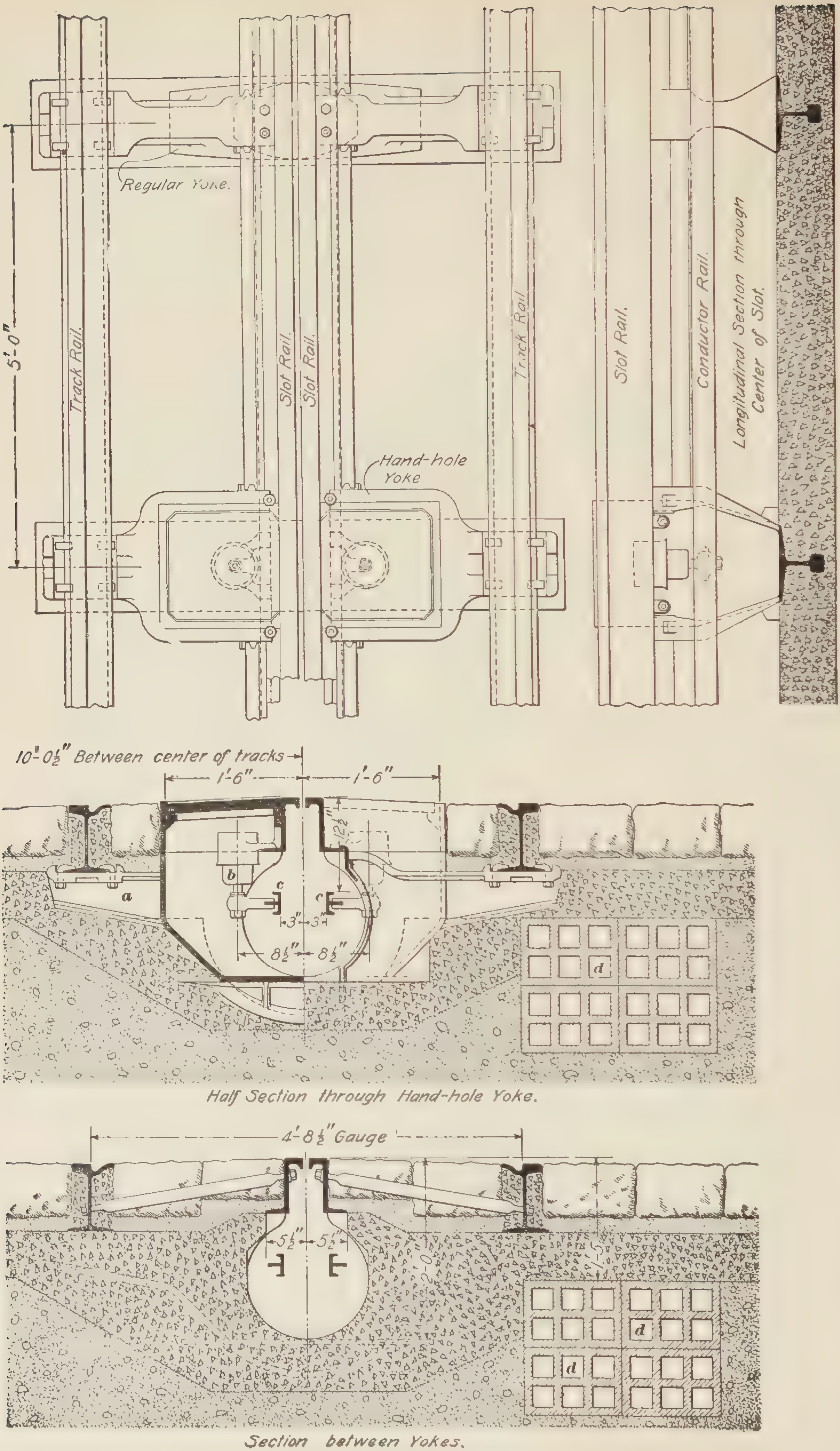


FIG. 51

On third-rail roads four shoes are placed on each car, one on each side of each truck, so that the car will always be supplied with current no matter on which side of the track the third rail may be placed.

CONDUIT ROADS

54. Fig. 52 shows a conduit construction, used in New York, that may be taken as typical of this class of roads. The rails are supported on heavy cast-iron yokes *a* spaced 5 feet apart; every third yoke is provided with handholes, as shown, and carries the insulators *b* to which the conductor rails *c*, *c* are fastened. The conductor rails are thus supported at intervals of 15 feet. Fig. 53 is a larger section of one of the handhole yokes, showing the method of supporting the conductor rail. The conduit between yokes is made of concrete filled in around a sheet-iron form that is afterwards



Regular Yoke.
5'-0"
Track Rail.
Slot Rail.
Slot Rail.
Track Rail
Hand-hole Yoke
Slot Rail.
Conductor Rail.
Longitudinal Section through Center of Slot.
10'-0½" Between center of tracks
1'-6"
1'-6"
a
b
c
c
3"
3"
8½"
8½"
d
Half Section through Hand-hole Yoke.
4'-8½" Gauge
5½"
5½"
d
d
Section between Yokes.

FIG 52

removed. Each manhole is connected to the sewer by a 6-inch pipe and the outgoing and return feeders supplying different sections of the conductor rails are run in terra-cotta ducts *d*, *d*, Fig. 52. To facilitate the installation of new feeders or the repair of old ones, manholes are provided every 400 feet.

55. Mud accumulates in the main conduit very fast, and if not promptly removed gives trouble. The main conduit must be cleaned about once a month in the summer time, and perhaps oftener than this during the winter. By means of special scrapers, the mud is drawn into the manhole and then lifted out and carted away.

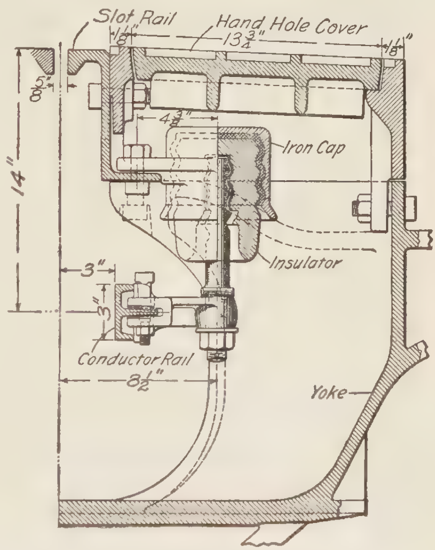
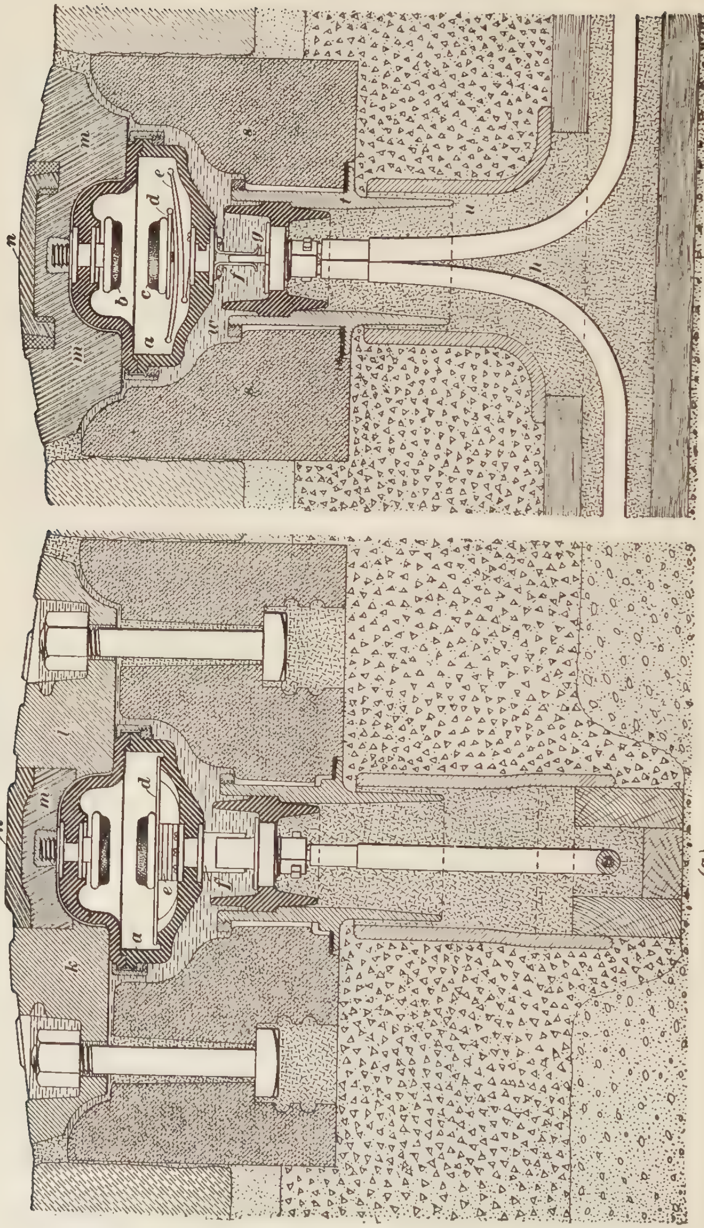


FIG. 53

The conductor rails are not continuous, but are divided into sections about a mile long, and each section is fed by its own feeder from the power house. There is no electrical connection between these feeders, so that the road is cut up into insulated sections, and trouble on one section is not so liable to interfere with the traffic on the others. Each feeder has its own switch and circuit-breaker, and in case a ground occurs on one section the circuit-breaker on that section flies out and the attendant in charge at the power house can tell exactly on what stretch of track the trouble is. Splitting the road into sections supplied by individual feeders also has the advantage that in case of a block on the road, the simultaneous efforts of all the motormen to start their cars will not cause heavy overloads in the power house,



(b)

(a)

FIG. 54

because the switchboard attendant has every section of the road under his control and can compel the cars to start up, one section at a time.

It is necessary that the yokes be well designed to resist the pressure of the earth (which is packed down by the heavy traffic) and the very heavy pressure in cold climates, due to the freezing of the soil, with its accompanying expansion. Wrought iron, steel, and cast iron have been used for this purpose, the latter, perhaps, being the most common. When yokes of light weight are put in, trouble is often occasioned by breakage. The conduit may be lined with steel plates or it may be constructed on the sides of concrete alone; in some cases the metal yokes have been replaced by concrete, but the best practice is to use heavy castings ranging in weight from 200 to 400 pounds or more, according to the depth of the conduit and the character of the wagon traffic expected.

SURFACE-CONTACT ROADS

56. As very few of these roads have been put into actual operation, the description here given will be confined to the system of the Lorain Steel Company, as successfully operated at Wolverhampton, England. The general principles of this system have already been described, and as the track rails and roadbed are installed in the same way as for an overhead system, it will only be necessary to explain the construction of the contact switches and the method of collecting current from them. Fig. 54 shows longitudinal and transverse sections of the contact switches placed between the rails, and Fig. 55 shows the relation of one of the magnets on the car, to the parts of the switch. The switch contacts, Fig. 54, are contained in a water-tight vulcabeston case *a* and take the form of carbon disks, *b* being fixed and *c* movable. The lower contact *c* is attached to an iron plate or armature *d* that is $4\frac{3}{4}$ inches long, 2 inches wide, and $\frac{1}{16}$ inch thick, and connected to the terminal clips *f* through a folded copper strip *e* that serves as a flexible connection and also guides the armature when it is drawn

upwards by the magnets on the car. The feeder cable connects to the fixed clip *g*, so that when case *a* is in place, contact *c* connects to feed-wire *h*. The cover consists of four parts, *k*, *l*, *m*, and *n*; parts *k* and *l* are of cast iron and *m* and *n* of hard manganese steel, which is practically non-magnetic. Piece *n* takes the wear of the collecting shoe and is renewable, being held in place by lead run in around it. The switch contact case is fastened to plate *m*, so that by removing the cover the whole case can be disconnected

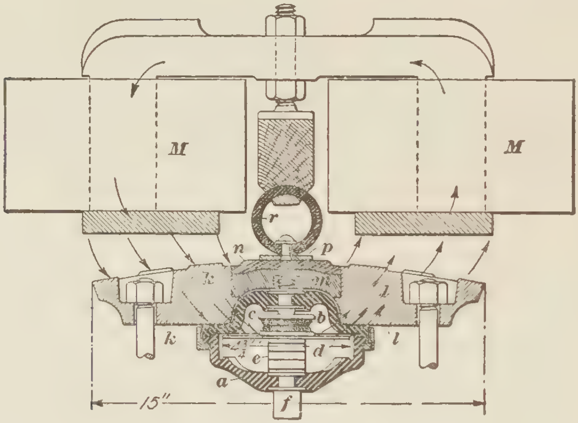


FIG. 55

from the feed-wire. The cover is bolted to a strong block *s s* of reconstructed granite and the feed-wire passes up through a cast-iron sleeve *t* that fits into a **Y** casting *u*; *t* and *u* are filled with insulating compound. Space *w* is filled with a heavy insulating oil that prevents moisture from accumulating around the live terminal *g* and thus avoids surface leakage. The contact studs are placed 10 feet apart.

57. The operation of the system will be understood from Fig. 55, where *M M* represents one of the magnets; the parts of the switch are lettered to correspond with Fig. 54. Six magnets are suspended under the car, extending over a space of 16 feet and, since the studs are only 10 feet apart,

the forward switch is operated before the back one is dropped and arcing at the switch contacts is avoided. The pieces of manganese steel m, n between the side blocks k, l are practically non-magnetic; hence, when a magnet is over a switch, as in Fig. 55, the lines of force take the path indicated by the arrows and pass through the light armature d, which is drawn up, thus bringing the carbon contacts together. As soon as the magnets move from the stud, armature d drops; and since the contacts are of carbon there is very little danger of their sticking. The collecting shoe consists of a flat copper strip p about 12 feet long bent up at each end and fastened to a piece of heavy rubber hose r, which provides pressure between the shoe and the studs and at the same time permits considerable flexibility. The shoe is long enough to bridge across two contact studs, thus providing a continuous collection of current. The magnets are compound wound. When the car is at rest, the shunt winding keeps the contact switches closed, so that the car can be started; the series winding provides excitation in case the voltage becomes too low for the shunt winding to operate the switches; it also holds the switches more firmly in contact as the current taken by the car increases. An eight-cell storage battery is provided on each car so that the series winding can be excited when the car is started for the first time or in case the power is shut off the line temporarily.

LINE CALCULATIONS

ECONOMICAL USE OF FEEDERS

1. There is no problem involving as little prospect of ever having general rules laid down to cover all cases and all conditions as the problem of calculating the most economical amount of copper to install and the best method of disposing that copper to meet the requirements of a given street-railway service. It is true that the present practice of dividing the line into insulated sections has, to a certain extent, simplified the work of calculation, because each section can be considered as an independent line governed by its own local conditions of load. If these conditions of load could in any case be laid down with certainty, the problem for any particular case would be solved; but once solved for that case, the solution would be of little use to the engineer for application to other cases, because it is almost impossible to find any two roads or even any two sections of the same road that call for the same conditions of load, and therefore for the same distribution of copper. During one part of the day the heaviest load might be on one part of the line and later in the day it might be on a section several miles away. Again, there may take place gradually a general shifting of the load more serious than a daily or weekly shift, due, possibly, to changes of attractions from one end of the line to the other, by a shift in the field of suburban improvements. Though overhead work may be installed under a design that meets satisfactorily almost every requirement of the present service, subsequent changes, such as the development of suburban property, may throw the system completely out of balance. The only thing to do then is

to go over the work again and put copper where it is needed. But it is now a well-known fact that in promiscuously putting up copper, although it may be placed with good judgment from an electrical point of view and successfully fulfil its mission of raising the voltage to its normal value at the desired point, it can be put at a net loss to the company. Copper is expensive, and in the effort to lessen the loss in the line, it is an easy matter to get so much copper strung that a condition arises where the money invested in copper might be more profitably invested in other ways, as, for example, in the installation of boosters or storage batteries.

2. The conditions that confront the engineer, then, when he proposes to improve the service by stringing more feeders are as follows: By thus raising the voltage, a certain amount of energy is saved by reducing the line loss, and the saving in watts or horsepower can be approximately calculated. By knowing what it costs to produce a unit of energy at the power house, the direct saving effected by the increase of copper can be at once obtained, and by knowing the cost of the additional copper installed, including the cost of construction, the interest on the cost of the copper may be computed. The rule that it pays to install more copper to raise the voltage, if the cost of the watts saved in a year exceeds a year's interest on the cost of the additional copper put up, is one that should always be kept in mind. It must not be forgotten, however, that the above limiting condition expressed in the form of an equation (interest on the cost = value of energy saved) does not include all the elements that modify the equation. When the feeding system is improved, it brings about a saving in a direct way; it makes the loss in the line less, and effects a saving in an indirect way that is just as important; for, by keeping up the voltage and thereby increasing the efficiency and speed at which the cars run, it not only decreases the number of cars necessary to conform to the conditions of a certain time table, but by improving the service it attracts travel, especially in cases where there is a competing road. Even in cases where there

is no competing road, an improvement in the service draws travel. Calling Q the interest on the cost, W the value of the energy saved, and S the money returned per year as a result of the raising of the E. M. F. by the additional copper, the modified equation will read (the present one reads $Q = W$) $Q = S + W$. This equation is more in favor of the added copper and conforms more to the true state of affairs.

EXAMPLES OF FEEDER CALCULATION

3. In the transmission of current for electric railways, as in other cases of electric transmission, the loss or drop in the line is usually limited. If the loss is large, a comparatively high-resistance line with a corresponding small amount of copper can be used, but a large line drop means a low voltage at the cars unless the voltage at the station is automatically increased as the load increases. Low line voltage makes it hard for the cars to maintain their schedule and always gives rise to trouble with the motors, to say nothing of the actual cost of the power wasted in the line. It is seldom that the average drop is less than 10 per cent. (50 volts), and in a great many cases it runs much higher than this; if feeding is accomplished through boosters, the line drop may be as great as 200 volts. These figures are for the average drop, and the maximum drop may at certain instants be as high as three or four times the average if the load is of a very fluctuating character.

4. The weight of the rail is fixed by traffic considerations, so that an approximate estimate of what the drop in the return circuit will be can be formed at the outset. The balance of the drop will then give that allowed for the feeders, and they should be designed to conform to this as nearly as possible. Feeders designed under this condition seldom fail to fulfil the requirements of the average drop. There is a great difference between the maximum and average loads in the stations, and the smaller the station, the greater is the difference liable to be. For this reason, the

average drop and maximum drop may be widely different. Take a case where the road operates only two or three cars and the load fluctuates between zero and the maximum several times in a minute. Before the size can be assigned to the feeders, the average load that each feeder has to look after must be approximately known or ascertained. In doing this, it is very convenient to divide the line into sections, assign to each section the load that probably will be on it, and proportion the feeders accordingly.

5. When the size, number, weight of cars, speed, type of equipment, etc. are known, the average current required for any given section of the road can be determined approximately, as described in a previous section and, knowing the current and allowable drop, the size of the feeders can be calculated. For purposes of illustration in the following examples, a current of 25 amperes per car is taken. This is a fair average for a 24-foot body car. Of course the current taken at starting is very much greater than this, but on the other hand when the car is standing still it is taking no current at all, so that 25 amperes may be safely taken. Also, in all examples, the trolley wire is No. 00 and its cross-section is taken as 133,000 circular mils, this being close enough for line calculations; its resistance per mil-foot is also taken the same as that of ordinary soft copper. This is not strictly accurate, because the resistance of hard-drawn copper is slightly higher than that of annealed copper, but it simplifies the calculations to consider them the same, and since the other quantities used in the calculations are necessarily approximate, there is no advantage in considering the slight difference in the conductivities of the two kinds of copper. Single track laid with 80-pound rail is assumed in all cases; the resistance per mile of track (two rails in parallel) will therefore be .028 ohm, assuming that the resistance across joints is no greater than that of an equal length of solid rail. In order to make some allowance for imperfect joints we will add 25 per cent. and take the resistance per mile of track as .035 ohm.

ROAD FED FROM ONE END

6. Fig. 1 shows the layout of a road 5 miles long. The system is fed from a power station at one end of the line and operates ten cars using on an average 25 amperes each, making a total of 250 amperes. It is specified that the total load concentrated at the end of the line shall not produce an average drop of over 100 volts. If the trolley wire is No. 00, what must be the size of the feeder *B A*?

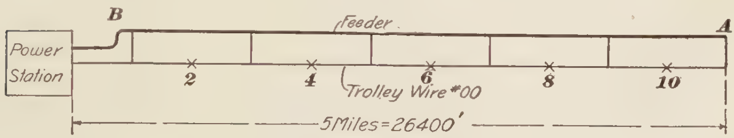


FIG. 1

The road is single track, so that the resistance of the 5 miles will be $.035 \times 5 = .175$ ohm, which resistance, carrying a current of 250 amperes, will cause a drop of $250 \times .175 = 43.75$ volts, leaving a drop of $100 - 43.75 = 56.25$ volts in the trolley wire and feeder. If it is assumed that the conductivity of the copper in the trolley wire is the same as that in the feed-wire, we may use the formula

$$\text{circular mils} = \frac{10.8\, L\, I}{e} \qquad (1)$$

where L = length of wire, in feet, through which the current I is delivered;

I = current supplied;

e = drop in volts.

The number of circular mils given by this formula will be the combined cross-section of the trolley and feeder, because these two wires are tied together in parallel throughout their length. In this case, $L = 26,400$ feet, $I = 250$ amperes, $e = 56.25$ volts; hence,

$$\text{circular mils} = \frac{10.8 \times 26,400 \times 250}{56.25} = 1,267,200$$

The trolley wire is No. 00, has an area of cross-section of 133,000 circular mils, and, deducting this from the total cross-section as calculated, leaves $1,267,200 - 133,000 = 1,134,200$

circular mils as the cross-section required in the feeder; two 500,000-circular-mil cables could be used and the system worked with a drop slightly larger than that calculated.

7. It should be noted that in working this example a fair value for the track resistance was assumed and the drop in the track circuit estimated. This was subtracted from the total drop, thus giving the value e used in formula **1**. Formula **1** does not, therefore, in itself take the track resistance into account. It was found that a very large feeder was needed to meet the requirements, which in this case were severe, because the drop was not to exceed 100 volts when all the cars were bunched at the end of the line. In most cases the cars would be moving along over different sections of the line, and thus lessen the drop on the system, because some of the cars would be comparatively near the station. At the same time, conditions arise where the cars may all be bunched at the end. In this case, therefore, it would be well to raise the voltage to 600 at full load at the station, either by using a heavily overcompounded generator, or by means of a booster.

POWER HOUSE IN MIDDLE OF LINE

8. If the power house were situated at the middle of the line, the amount of copper required would be very much less, as will be easily seen by referring to Fig. 2. The limiting condition is the same as before; that is, the drop

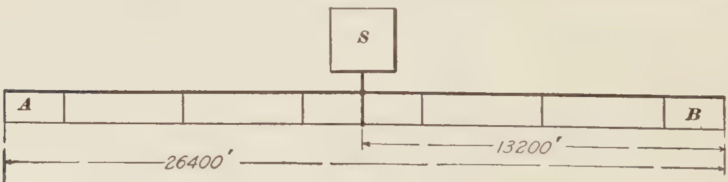


FIG. 2

from S to A or B must not exceed 100 volts when all the cars are concentrated at either A or B. If the cars are bunched at either A or B, 250 amperes must be transmitted through $2\frac{1}{2}$ miles of track and feeder. Taking the track

resistance as .035 ohm per mile, the resistance of $2\frac{1}{2}$ miles of track will be $.035 \times 2.5 = .0875$ ohm. The drop in the track part of the circuit will, therefore, be $.0875 \times 250 = 21.875$ volts. This leaves a drop of $100 - 21.875 = 78.125$ volts in the feeder and trolley wire. The length of feeder and trolley wire is $2\frac{1}{2}$ miles; hence, by applying formula **1**, the combined cross-section of the two is

$$\text{circular mils} = \frac{10.8 \times 13{,}200 \times 250}{78.125} = 456{,}190$$

The trolley wire supplies 133,000 circular mils of this cross-section; hence, the cross-section of feeder required is $456{,}190 - 133{,}000 = 323{,}190$. Placing the power house near the middle of the line results in a very large reduction in the amount of copper required, and a single 300,000-circular-mil cable would supply the current with as little drop as two 500,000-circular-mil cables in the first example.

EFFECT OF DISTRIBUTED LOAD

9. So far the feeder problems have been worked out on the assumption that the load was bunched at one end. This is a condition that sometimes arises in practice, but it can hardly be looked on as the ordinary operating condition. In most cases, a number of cars are spaced at fairly regular intervals along the line, each car moving at an approximately

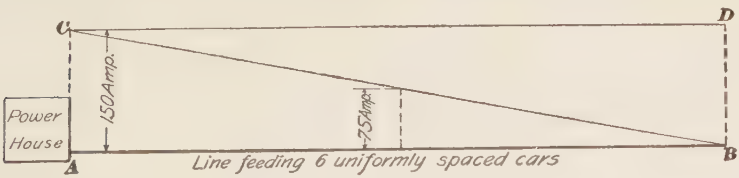


FIG. 3

uniform rate with the result that current is taken off at a number of points that are continually shifting. The load is nearly uniformly distributed and there is a gradual falling off in current from the station to the end of the line. For example, suppose that AB, Fig. 3, represents a stretch of line that supplies six uniformly spaced cars moving at a

uniform speed and taking 25 amperes per car. On account of the uniform movement and even spacing, the current will decrease gradually from 150 amperes at the station to zero at the end B. We may represent the falling off in the current by the line CB. The drop between A and B will, therefore, be found by multiplying the average current in AB by the resistance. The average current is evidently one-half the station current, or 75 amperes; hence, if the resistance of AB is, say, $\frac{1}{2}$ ohm, the drop between A and B will be 37.5 volts. If the whole load is bunched at B, the current will be 150 amperes throughout the whole length, as represented by the line CD, and the average current throughout the length will be the same as the current at the station; hence, the drop will be $150 \times \frac{1}{2} = 75$ volts. Hence, for a given line wire and a given amount of current transmitted, the drop with a uniformly distributed load is one-half that with a concentrated end load. In other words, if calculations are made relating to a distributed load and the whole length of line is considered in the calculations, the current must be taken as one-half the actual current supplied to all the cars, because it falls off from the station, or feeding point, to the end of the line.

Another and perhaps a better way of considering a distributed load is to look on it as if the whole load were concentrated at the middle of the line and work out the problem as if the whole current were transmitted over half the line.

10. Example of Calculations for Distributed Load. Taking the road shown in Fig. 1, find what size of feeder will be required when the load is distributed and the average drop to the end of the line limited to, say, 50 volts.

There are ten cars, each taking 25 amperes and uniformly spaced; the whole load of 250 amperes may be considered as concentrated at the middle of the line, or that an average current of 125 amperes is transmitted over the whole line. In order to be definite, we will work the problem as if 250 amperes had to be transmitted through $2\frac{1}{2}$ miles of feeder and $2\frac{1}{2}$ miles of track with a drop of 50 volts. The

track resistance is .035 ohm per mile and the resistance of $2\frac{1}{2}$ miles of track is .0875 ohm; the drop in the track is $.0875 \times 250 = 21.875$ volts. This leaves $50 - 21.875 = 28.125$ volts drop for the feeder and trolley. Then the combined cross-section of the feeder and trolley will be circular mils $= \frac{10.8 \times 13{,}200 \times 250}{28.125} = 1{,}267{,}200$. This combined cross-section is the same as that necessary to supply an end load with a drop of 100 volts. In other words, with the same amount of line copper, a uniformly distributed load will produce only one-half the drop that a bunched end load will cause, or if the drop is kept the same in both cases, the amount of copper required for the distributed load will be only one-half that called for by the concentrated load.

The method of working out the case shown in Fig. 2, for a distributed load, will be the same as the above except that the current supplied on each side of the station will be only 125 amperes, because the load is uniformly distributed and one-half the cars will be on each side. Also, this 125 amperes will be considered as concentrated at the middle of the 13,200 feet. This will require much less copper than when the load is concentrated at either end. In the above, it must not be forgotten that while the load is considered as bunched at the middle of the line, the feeder runs the whole length, as indicated in the figures.

CALCULATIONS FOR A LOOP LINE

11. Fig. 4 represents a so-called **loop line** that runs down one street and comes up at the next street parallel to it. It is a modified form of the **belt line** that is supposed to encircle the business part of the city, but it differs from a belt line in that, since the parallel lines are in neighboring parallel streets, the power house can, without great sacrifice of economy, be placed to one side of the area enclosed by the system, instead of being placed within this area.

In Fig. 4, AC is the street that the cars go up, DB the street on which they return. The area enclosed by the two tracks is very long in comparison to its width, but the width

between the streets is exaggerated in Fig. 4 in order to make the arrangement clearer. The track is represented by the parallel dotted lines, and the two trolley wires are tied together at intervals. Two feeders, represented by the heavy lines, are connected to the trolley wires at points l, m, and the trolley wire is divided into two sections by means of section insulators x, x', each feeding-in point being at the middle of a section. Since the two sections are independent and each is supplied by its own feeder, it will be sufficient to calculate one of the feeders; the other will be the same, because the road is symmetrical. Since the cars are uniformly distributed, the load on each section may be considered as

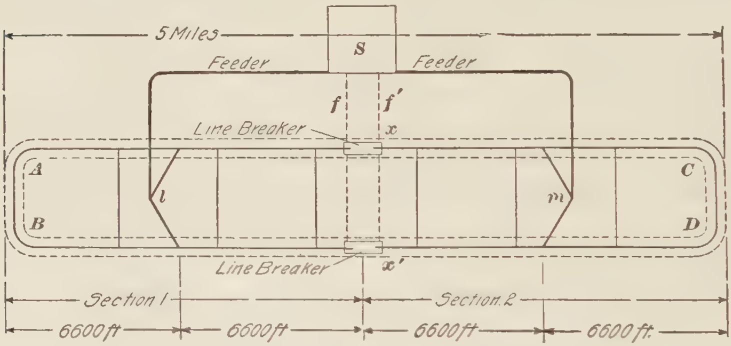


FIG. 4

concentrated at the middle of that section, that is, where the feeders are attached. The drop from the station to the feeding-in points l, m must not exceed 50 volts, and a total of ten cars is operated, each taking 25 amperes. The number of cars on each of the two sections will, therefore, be five, and each feeder will have to supply 125 amperes. Since the trolley wire is fed from the middle point of each section and there are no feeders on the end of the section, there will always be more or less drop in the trolley wire itself, but this will not be very great because there will not be more than two cars on any trolley section, and if the drop to the feeding-in points is limited to 50 volts the service will be satisfactory. The length of a section is $2\frac{1}{2}$ miles, or

13,200 feet; a half section is 6,600 feet. The resistance through which the drop of 50 volts is to take place is that of four lines of single rail well bonded together, each line being $2\frac{1}{2}$ miles long. However, the load is uniformly distributed and the total current of 125 amperes can be considered as flowing through $1\frac{1}{4}$ miles of double track. The resistance of 1 mile of single track is .035 ohm and of double track $\frac{.035}{2}$; hence, $1\frac{1}{4}$ miles of double track has a resistance of $\frac{.035}{2} \times \frac{5}{4}$ $= .0219$ ohm. The drop in the rail return is $.0219 \times 125$ $= 2.74$ volts, and the allowable drop in the feeders $50 - 2.74 = 47.26$ volts. So far as the feeders are concerned, the load is not distributed because they each connect to the trolley wire only at the end, and 125 amperes is carried over the whole length of the feeder. The length of the feeder is 6,600 feet; hence, circular mils $= \frac{10.8 \times 6{,}600 \times 125}{47.26}$ $= 188{,}530$, approximately.

No. 000 B. & S. is too small (167,805 circular mils) and No. 0000 (211,600 circular mils) is larger than the calculated size; however, it would be advisable to use No. 0000 and thus allow for a future increase in load. The drop in the feeder can be calculated from formula **1** transposed to read

$$e = \frac{10.8\, L\, I}{\text{circular mils}} \qquad \textbf{(2)}$$

which for a No. 0000 feeder (211,600 circular mils), gives

$$e = \frac{10.8 \times 6{,}600 \times 125}{211{,}600} = 42.1 \text{ volts, nearly}$$

12. In the layout shown in Fig. 4, the trolley wires are not fed on the ends, and if the five cars on one-half of the road became bunched at the end of a trolley section the drop would be considerable. Under these conditions, 125 amperes would be carried 6,600 feet by two No. 00 wires in parallel and the drop in the trolley wire would be, from formula **2**,

$$e = \frac{10.8 \times 6{,}600 \times 125}{2 \times 133{,}000} = 33.5 \text{ volts}$$

13. In Fig. 4, suppose that two feeders f, f', indicated by the dotted lines, are connected, one to each section, directly from the power house. In practice, it will cost but little to do this, because these feeders are very short and, as shown by the following, the effect on the voltage is beneficial. Consider one of the sections, say, section *1*; it is fed by the regular feeder previously calculated, and, in addition, the feeder f runs out directly from the power house and is tapped on the trolley wire at the line breaker. We will find what the drop would be under the most unfavorable conditions, that is, with the five cars on the section bunched at A. The whole current, 125 amperes, will have to return to the station through $2\frac{1}{2}$ miles of double track. In the overhead work there will be $1\frac{1}{4}$ miles of feed-wire, and in parallel with this will be the two trolley wires extending back to the station, because the connection of the feeder f places the trolley wires in parallel with the regular feeder. Up to the point l, therefore, the feeder and the two trolley wires, in parallel, carry the current; beyond l, to the end of the line, the current is carried by the two trolley wires alone. It will be assumed that No. 0000 wire is used for the feeder.

The resistance of $2\frac{1}{2}$ miles of double track will be $\frac{.035}{2} \times \frac{5}{2}$ = .0438 ohm, approximately. The drop in the track will, therefore, be $.0438 \times 125 = 5.475$ volts, or say, 5.5 volts. From l to A, the drop in the two trolley wires will be 33.5 volts. From the station to point l, there is a No. 0000 feeder in parallel with two No. 00 trolley wires; hence, the total cross-section of copper is $211,600 + 2 \times 133,000 = 477,600$ circular mils. The drop from the station to point l is therefore

$$e = \frac{10.8 \times 6,600 \times 125}{477,600} = 18.7 \text{ volts, nearly.}$$

The total drop from station to cars is the sum of the drops in the different portions of the circuit, or $5.5 + 33.5 + 18.7 = 57.7$ volts.

If feeders f, f' were not provided, the drop with five cars bunched at A would be $5.5 + 33.5 + 42.1 = 81.1$ volts. Adding feeders f, f', therefore, effects a reduction of 23.4

volts in the drop under the most unfavorable conditions. If the load were concentrated at the power-station end of the section, there would be little or no resistance in the circuit, save that of the tap wire and the ground-connection wire, so that it is safe to say that the loss caused by a current of 125 amperes would not at this point be more than 5 volts. The power-house taps, as well as the line feeder, should be provided with feeder switches, so that the current can be cut off at any section desired.

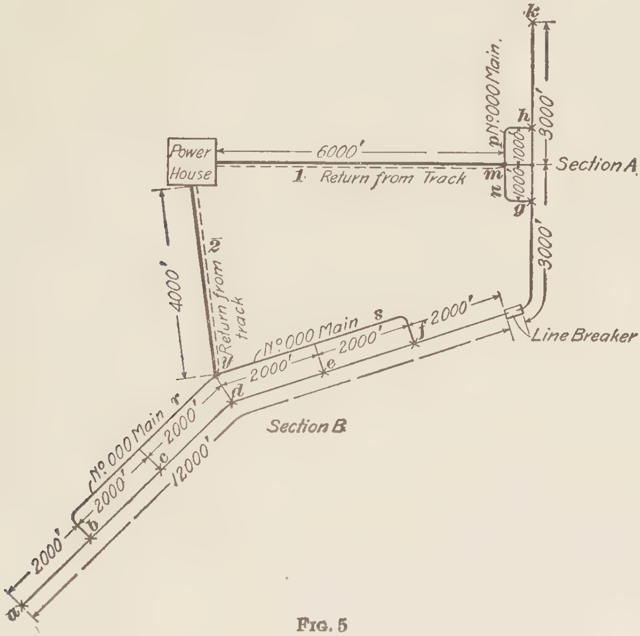


FIG. 5

SMALL ROAD WITH RETURN FEEDERS

14. To illustrate the calculations for a road where the power house is not situated alongside the track and where return feeders must be run, the following example will be taken:

EXAMPLE.—Fig. 5 shows the layout of a single-track road operating nine cars, which are spaced fairly evenly along a line divided into two sections by means of a line breaker. The sections are provided with

No. 000 mains, fed by two feeders *1* and *2* running from the power station. Return feeders, represented by the dotted lines, are run alongside the outgoing feeders and the drop under average conditions is to be limited to 50 volts. Each car takes an average current of 25 amperes, the track is laid with 80-pound rails, and the trolley wire is No. 00.

Solution.—Since the cars are equally spaced and constantly shifting in position, the drop will vary somewhat, depending on the position of the cars. In order to make things definite, we will assume that the cars are located as shown by the crosses. This will represent a fair average condition, and the drop for other positions will not be greatly different unless the cars become bunched. If the feeders are designed so that the drop from the power house to cars *a* and *k* will not exceed 50 volts, it is evident that the drop to the other cars will fall under the prescribed 50 volts, because cars *a* and *k* are the most distant from the station. A single track laid with 80-lb. rails has a resistance of .0053 ohm per 1,000 ft., assuming the joints to be perfect; in order to allow for imperfect joints we will take the resistance per 1,000 ft. as .0065 ohm. The conductivity of the copper in the trolley wire may be taken the same as that in the distributing mains and feeders, and it will be sufficiently accurate to take the cross-section of the No. 00 trolley wire as 133,000 cir. mils and the No. 000 mains 167,800 cir. mils. First take section *A* and determine the size of feeder *1*.

Section A.—The road operates nine cars and is 18,000 ft. in length; hence, there will be one car for every 2,000 ft. Section *A* will have three cars and the current supplied by feeder *1* will be 75 amperes. The sizes of trolley wire and distributing main are fixed so that the drop in these and in the track must first be determined; the remainder will then be the allowable drop in the outgoing and return feeders. The ground-return feeder taps in at the center of each section so that for the upper half of section *A* there will be 25 amperes flowing back from *k* through 2,000 ft. of track and 50 amperes back from *h* through 1,000 ft. of track. The drop through the stretch of track *k m* will therefore be $25 \times .0065 \times 2 + 50 \times .0065 \times 1 = .65$ volt. The wire has a cross-section of 133,000 cir. mils, is 2,000 ft. long, and carries 25 amperes; hence, drop $e = \frac{10.8 \times 2{,}000 \times 25}{133{,}000} = 4.06$ volts.

From *m* to *h*, the trolley wire is in parallel with a No. 000 main; hence, the total copper cross-section is $133{,}000 + 167{,}800 = 300{,}800$ cir. mils; the current is 50 amperes, and drop $e = \frac{10.8 \times 1{,}000 \times 50}{300{,}800} = 1.79$ volts. The total drop between *m* and *k* and in the track-return circuit will be $.65 + 4.06 + 1.79 = 6.50$ volts, thus leaving $50 - 6.50 = 43.5$ volts for the drop in the outgoing and return feeders.

The current in feeders *1* is 75 amperes, and the total length (outgoing and return) 12,000 feet; hence, circular mils of feeders for section $A = \frac{10.8 \times 12{,}000 \times 75}{43.5} = 223{,}450$, approximately. Either No. 0000 B. & S. wire (211,600 cir. mils) or a 300,000-cir.-mil cable can be used for these feeders, the latter being preferable.

Section B.—The drop in the track from *a* to *d* will be $25 \times .0065 \times 2 + 50 \times .0065 \times 2 + 75 \times .0065 \times 2 = 1.95$ volts. In the overhead work, the drop between *a* and *b* in the trolley wire will be the same as from *k* to *h* in section *A*; i. e., 4.06 volts. The drop between *b* and *c* will be twice that between *h* and *m* in section *A* because the current and sizes of wires are the same but the distance is twice as long; hence, the drop from *b* to *c* is $1.79 \times 2 = 3.58$ volts. Car *d* will cause no drop in the track or overhead work because its current is taken directly from the feeder. The drop between *c* and *d* will be that due to 75 amperes through 2,000 ft. of combined trolley and main; hence, drop $e = \frac{10.8 \times 2{,}000 \times 75}{300{,}800} = 5.4$ volts, nearly. The total drop between *a* and *y* is therefore $1.95 + 4.06 + 3.58 + 5.4 = 14.99$, or say, 15 volts, leaving $50 - 15 = 35$ volts for the drop in the outgoing and return feeders. The current in feeders *2* will be that due to six cars, or 150 amperes, and the total length of feed-wire is 8,000 ft.; hence, circular mils of outgoing and return feeders for section $B = \frac{10.8 \times 8{,}000 \times 150}{35} = 370\ 286$. For these feeders 350,000-cir.-mil cable will be suitable.

CARRYING CAPACITY OF FEEDERS

15. In making these calculations, no attention was paid to the carrying capacity of the wires and cables. Of course, this point must be kept in mind, because if the lines are simply figured out on the basis of giving the allowable drop, it might happen that the current would overheat the wires. Table I, due to Mr. H. W. Fisher, gives the approximate amount of current that wires may be allowed to carry without causing the temperature to increase much over 25° F. above that of the surrounding air.

In most cases, however, it will be found that the size of wire needed to keep the drop within the specified limits will be considerably larger than that necessary to carry the current without overheating. Only in cases where the distances are short is there likelihood of the wire not being large enough. It is always well, however, to compare the

TABLE I

CURRENT-CARRYING CAPACITY OF FEEDERS

No. B. & S. Gauge	Circular Mils	Carrying Capacity, With a Rise in Temperature of 25° F., Approximately Amperes	No. B. & S. Gauge	Circular Mils	Carrying Capacity, With a Rise in Temperature of 25° F., Approximately Amperes
Stranded Cables	500,000	509	2	66,370	124
Stranded Cables	400,000	426	3	52,630	107
Stranded Cables	350,000	388	4	41,740	91
Stranded Cables	300,000	355	5	33,100	74
Stranded Cables	250,000	319	6	26,250	63
0000	211,600	275	7	20,820	52
000	167,800	237	8	16,510	44
00	133,100	195	9	13,090	36
0	105,500	168	10	10,380	30
1	83,690	143			

sizes obtained and the current that the wires must carry with the values given in the table. If the wires should prove to be too small, the only thing to do is to use a wire that will carry the current safely or else run the risk of the wire overheating. If the larger wire is used, it will result in a somewhat smaller drop, but this will be an advantage, although the first cost of the wire will be a little higher.

16. Effects of Low Voltage.—If the drop becomes excessive, either on account of the feeding system being too light or the load too heavy, it will produce a low voltage at the cars, and this in turn means low speed. It is a well-known fact that just as soon as the voltage on a system becomes low, troubles with the motors and car equipment begin to multiply. There are many cases on record where controller and brush-holder troubles have been very much decreased and where the roasting of field coils, controller blow-out coils, and the throwing of solder out of the commutator

connections have been entirely stopped simply by raising the voltage on the line.

Suppose that a road having a certain number of cars is operated at, say, 550 volts and on a certain schedule; also, suppose that owing to an extension of the road, the addition of more cars, the deterioration of the track-return circuit, or any other reason, the voltage gradually comes down to 400. This will make a maximum decrease of about 20 per cent. in the running speed of the cars. If the time table is rearranged so that the motormen can run the cars on time with the same ease that they could with the higher voltage, the troubles with the rolling stock will not only not increase, but they will actually decrease, because the lower voltage is not as hard on the insulation and arc-breaking devices and the lower speed is not as hard on the car bodies and trucks.

If, on the other hand, no notice is taken of the gradual decrease in the average line voltage and the same time table is kept in force, the following will be the result: Since the maximum running speed of the cars has been cut down, the motorman must make up time wherever he can. Most of this will be made up at starting and getting the car under headway; part of it will also be made up on curves, crossings, and other places where, under ordinary conditions, slow running would be the rule. At starting, the controller is moved around rapidly and the car takes far more current than it should and the excessive current injures the controller, the commutator, and the brushes. The insulation on the fields becomes roasted and troubles of all kinds are liable to occur simply because the equipment has to be abused to make the car run on time.

As a practical instance of the result of low voltage, the following actual case that occurred where two abutting roads used each other's tracks for about $\frac{3}{4}$ mile may be cited. Their trolley wires were separated by a line breaker and each road had its own feeder system. On one side of the breaker the voltage was 425 volts; on the other side, 525 volts. As long as each road used only its own trolley wire the

high-voltage road had no trouble to speak of. As soon as its cars began to run over the low-voltage road, controller and brush-holder breakdowns set in and continued until two extra feeders were run to the low-voltage side.

The above effects have been noted here simply to show that the question of proper voltage is an important one. It is true that there are many roads operating under an excessive drop, and this in itself is not so bad if the pressure at the station is increased so that the proper voltage at the cars is maintained. At the same time, a large drop means a large waste of power, and the question as to whether it will pay better to lose a considerable amount of power or buy more feed-wire is something that must be determined by the relative cost of power and copper.

ELECTROLYSIS

17. Introductory Remarks.—The subject of **electrolysis,** by which is here meant the eating away of the rails, underground pipes, or other buried metallic conductors by stray currents from the street-railway system, is closely connected with the feeding system, especially with the track-return part of it. When electrolysis was first noticed, a great outcry was raised against the trolley roads by gas and water companies, telephone companies, and other corporations owning underground pipes or lead-covered cables. The many lawsuits brought against electric-railway companies led to an investigation of the subject, with the result that electrolysis is not feared nearly as much as it once was, because means have been devised for avoiding it largely or for limiting it to sections where it can be watched or provision made to prevent it.

18. Elementary Principles.—In Fig. 6, *A* and *B* are two iron plates buried a short distance apart in damp earth. If the terminals of *A* and *B* are connected to a dynamo and a current made to flow from *A* to *B* through the earth, plate *A* will be eaten away or pitted while plate *B* will not

be damaged. This is practically the same electrochemical effect that takes place in electroplating, where metal is taken from a plate, or anode, and deposited on the article to be plated. The point to notice is that wherever current flows *from* a metal conductor into damp earth, the conductor is eaten away, provided that the difference of potential between the conductor and the adjacent earth is sufficient to effect the chemical decompositions; but where current flows from the earth *into* the conductor, the latter is not damaged. The rate at which the metal will be eaten depends on the strength of the current.

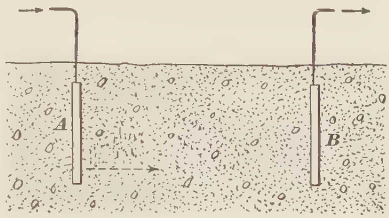


FIG. 6

19. Table II shows the weight of metal that will, theoretically, be eaten away by 1 ampere flowing steadily for 1 year, for metals likely to be affected by stray underground currents.

TABLE II

ELECTROLYTIC EFFECT OF CURRENT ON VARIOUS METALS

Metal	Grams per Ampere-Hour	Pounds per Ampere per Year
Aluminum	.327	6.31
Copper	1.190	22.97
Iron	1.044	20.15
Lead	3.852	74.34
Tin	2.218	42.71
Zinc	1.216	23.47

This table is of interest chiefly because it shows the relative effect of a current on the different metals. It does not follow that in practice, whenever a current of 1 ampere flows

for 1 year from a conductor into the ground, the amounts of metal indicated by the table will be eaten away. In fact, under some circumstances current may flow from a buried conductor to the ground without eating the metal at all. For example, the ions liberated by the current may be such that no corroding action takes place on the pipe, or the energy expended per unit area of the pipe surface may not be great enough to decompose the salts in the damp earth. It has also been found in many cases that electrolytic action may take place for a while and then cease owing to the character of the earth around the conductor having become changed by the decomposition of the salts contained therein and rendered incapable of acting as an electrolyte for further electrolytic action. It should also be remembered that underground pipes and conductors may become corroded by the simple chemical action of the salts contained in the earth, and whenever a conductor or pipe shows signs of pitting it by no means follows that the corrosion is due to electrolysis; in fact, there is no sure way of telling simply from the appearance of the pipe to which source the corrosion is due.

Mr. Albert B. Herrick* suggests the following method for determining definitely whether or not corrosion is due to simple chemical action or to electrolytic action. The pipe in question is uncovered for about 8 feet of its length. Half-round test shields made of material as nearly like the pipe as possible and of inside diameter corresponding with the outside diameter of the pipe, are provided; the length of these is usually about three times the diameter of the pipe to be tested. A length of the pipe corresponding to the length of shield is carefully cleaned and amalgamated, and the inside surfaces of a pair of shields are similarly treated. The shields are then firmly fastened to the pipe by bolting the semicircular halves together by means of bolts passing through projecting flanges. Another pair of plates is also bolted to the pipe, alongside of but not touching the first

*Street Railway Journal, Vol. XXIII, No. 14.

pair, and before bolting them in place the pipe is covered with a $\frac{1}{8}$-inch sheet of rubber. The second sheath is thus insulated from the pipe while the first is in good metallic contact with it and before being placed in position both shields are carefully weighed and notes made as to the character of their surfaces. The pipe and sheaths are then covered with earth and allowed to stand undisturbed for 6 months. At the end of that time they are examined, carefully cleaned, and weighed. If the insulated shield has been corroded it must have been on account of ordinary chemical action and the difference in weights will indicate the amount of corrosion. If the uninsulated sheath is corroded it may be due to electrolytic action, to ordinary chemical action, or to a combination of the two. By thus noting the difference in the effects on the two shields, the effects of corrosion from the two sources can be determined.

In Table II, it is interesting to note that lead is eaten away more rapidly than any of the other metals there given. Underground lead pipe, and the lead sheaths of underground cables are, under like conditions, eaten away much more rapidly than iron pipe. Also, wrought-iron pipe is much more susceptible to electrolytic corrosion than cast-iron; with cast iron the impurities in the iron appear to form a kind of scale that protects the pipe.

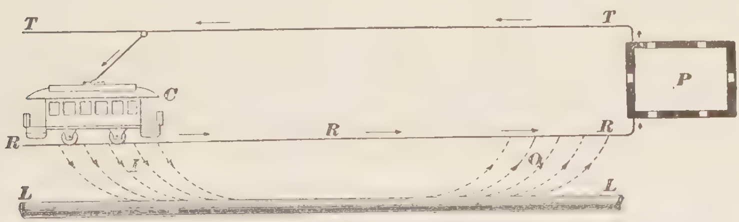


Fig. 7

20. Electrolysis Due to Railway Currents.—Fig. 7 gives a simple illustration as to how electrolysis may occur in connection with an overhead-trolley system. T T is the trolley wire and R R the track; under ordinary conditions, the current returns by way of the rail, as indicated by the

arrows. If, however, there happens to be a pipe $L L$, in the neighborhood of the track, that offers a ready path for the current, part of the current will leave the rails, as at I, enter the pipe, and flow out again at O to return to the power station. At O, where the current leaves the pipe, electrolytic action will be set up, if the conditions are favorable, and in the course of time will eat holes in the pipe. At I, the current leaves the

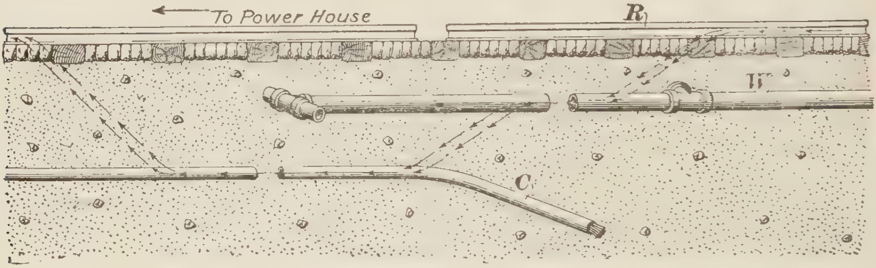


FIG. 8

rails; hence they will be eaten away to some extent. If the trolley wire were connected to the negative pole of the dynamo instead of the positive, the current would flow out through the track, and whatever corrosion occurred on the pipes would take place at points removed from the station and would be scattered over a wide area. On the other

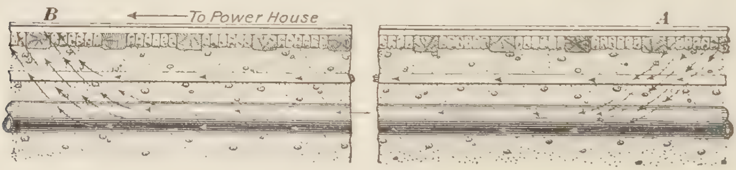


FIG. 9

hand, with the positive pole connected to the trolley, whatever action takes place on the pipes is confined to districts near the power house. These areas are comparatively small, and measures can be taken to protect them. This is the principal reason why the positive pole of the dynamo should be connected to the trolley side of the line. Figs. 8 and 9 show modifications of the simple case shown in Fig. 7.

In Fig. 8 the current leaves the rail *R*, enters the pipe *W*, and flows through *W* until a better path presents itself in the shape of the lead-sheathed cable *C*. It flows along *C* until the track presents a better path, when it flows back to the rail again, as indicated by the arrows. Electrolytic action may occur where the current leaves the rail, the iron pipe, and the lead sheath of the cable. Fig. 9 shows a case where a cable and pipe run parallel to the iron rail *A B*, the arrows indicating the path of the stray current. Lead-covered underground cables are particularly liable to damage, because lead is eaten away much more rapidly than iron; moreover, the corrosion never takes place evenly, but in spots, so that the pipe or sheath becomes pitted and is soon destroyed. However, the general practice now is to run underground cables in tile ducts which form an insulating medium between the cable sheath and ground, thus preventing electrolysis to a large degree. Wrought-iron pipes are more quickly eaten than cast-iron; in fact, the harder grades of cast iron, such as chilled iron, seem to be very little affected.

It is seen, by referring to Fig. 7, that if the track return is in good condition, there will be little inducement for the current to leave the track and pass through the intervening earth to come back on the pipes. One of the most effective precautions against electrolysis is thorough rail bonding. With the greater attention that is paid to rail bonding on modern roads, there has been a corresponding reduction in the damage due to electrolysis.

21. Testing for Electrolysis.—The difference of potential between a pipe and the track depends on the current flowing between the two and the resistance of the intervening earth. The difference of potential that is effective in producing electrolytic action is that which exists between a pipe and the earth immediately surrounding the pipe. A very small E. M. F. may be sufficient to cause electrolysis while the E. M. F. measured between pipe and track might be quite high because of the intervening resistance. In order for electrolysis to take place, the pipe must be positive to

the surrounding earth so that current will flow from the pipe to the earth. If a test shows that the earth is positive to the pipe there is no danger at that point so far as the pipe is concerned. The old method of testing between the pipe and rail with a millivoltmeter does not give reliable information as to the potential between the pipe and adjacent earth, and

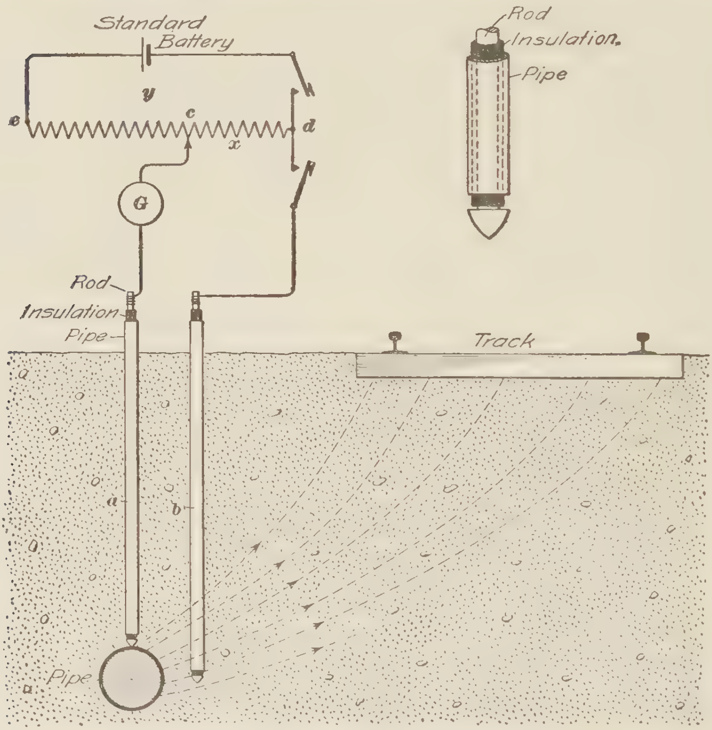


FIG. 10

the following test is recommended by Mr. Herrick as being much more reliable. An insulated pointed rod *a*, Fig. 10, is driven through the soil until the point comes in contact with the pipe. A second insulated rod *b* is driven in so that its point will come close to the pipe but will not touch it. Both rods are insulated and protected by running them through a piece of iron pipe lined with insulating material, as, for

example, a piece of lined conduit such as is used for wiring buildings. The earth potential point is covered with cadmium so that there will not be a local E. M. F. set up, which will disturb the difference of potential due to the earth currents. Also, the E. M. F. existing between the pipe and the test point is measured not by means of a voltmeter, which would disturb the normal current flowing between pipe and ground, but by balancing the unknown E. M. F. against a known E. M. F. from a standard battery. The resistance c is adjusted until the galvanometer indicates zero current, and the E. M. F. between pipe and ground then bears the same relation to the known E. M. F. of the standard battery that resistance x between c and d bears to the total resistance y included between e and d; or,

$$E_1 = E\frac{x}{y} \qquad (3)$$

where E_1 = E. M. F. between pipe and ground;
E = E. M. F. of standard battery;
x = resistance $c\,d$;
y = total resistance.

It is not necessary to know the values of x and y, in ohms; if the ratio of their resistances is known it is sufficient. Resistance y can be in the form of a bare high-resistance wire wound on a cylinder and provided with a sliding contact and scale, so that the divisions read off for any position of the contact will be proportional to the resistance x.

Example.—A test was made, as shown in Fig. 10, with a standard battery giving 5 volts and a sliding contact resistance divided into 100 equal parts. When the galvanometer gave no deflection, resistance x was represented by 30 divisions on the scale. What was the E. M. F. between the pipe and ground?

Solution.—In formula 3, since the resistances are proportional to the lengths of wire,

$$\frac{x}{y} = \frac{30}{100} \text{ and } E_1 = 5 \times \frac{30}{100} = 1.5 \text{ volts. Ans.}$$

22. Prevention of Electrolysis.—A large system of piping forms a conducting network of very low resistance in

parallel with the track, hence it is a very difficult matter to prevent part of the current from leaving the track. However, if proper steps are taken, the bad effects of electrolysis can be largely avoided; the following are the main points that experience has shown should be observed:

(*a*) The trolley wire should be made the positive side of the system.

(*b*) The track should be thoroughly bonded and the bonds maintained in good condition.

(*c*) Any metallic connections that may exist between piping or cable systems and the track should be located and removed.

(*d*) Return feeders should be run out from the station and connected to those pipes that carry the greater part of the current. Thus, the current in the pipes will be "drained" off without passing from the pipes to ground.

(*e*) Where service pipes, cables, or underground conductors pass under tracks or through other regions where they are exposed to electrolytic action, they can often be protected by covering them with glazed tile or by placing them in a trough filled with asphalt.

(*f*) If in any part of a system the rail return carries an excessive current, return feeders should be run so as to relieve the rail of part of the current and prevent an excessive fall of potential along the rail. The greater the fall of potential in the rails the greater is the tendency for the current to pass off to neighboring pipes.

The remedy given under (*c*) is important. Very often accidental connections exist between the rails and pipe so that current can pass directly to the piping system. This is specially the case where pipes run across iron bridges that also carry railway tracks. Before attempting to "drain off" the current from a piping system it is needless to say that all metallic connections between track and pipe must be removed. Where pipes pass across iron bridges the best plan is to insulate the pipe from the bridge, or if this is impossible, insulate the pipe by the insertion of insulating joints at either end of the bridge.

Remedy (*d*) is very commonly practiced and gives good results if properly applied. The return feeders should be attached to the pipes that carry the most current and, as a rule, the current so returned to the power house will not be more than 5 or 6 per cent. of the total current; if it exceeds this amount it is probable that there is a metallic connection somewhere between the track and pipes.

Service pipes crossing under street-car tracks are particularly subject to electrolytic action, and when they are being laid or repaired it costs but little to cover them with tile or to run them in a box, as explained in (*e*).

23. Method of Measuring Current in Pipe.—Fig. 11 shows a convenient method for measuring the current flowing in a pipe. Clamp terminals *a*, *b* are attached from 4 to 6 feet apart, and low-resistance connections made to an ammeter *c* through a switch *d*. A millivoltmeter *e* is also connected across terminals *f*, *g*, and readings taken from it with the switch *d* open and readings taken from *e* and *c* with *d* closed. The reading of *e* will be less when *d* is closed, as then part of the total current flows through the ammeter circuit. The current flowing in the pipe is then obtained from the formula

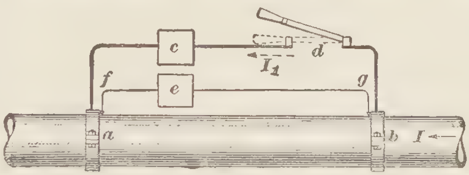


FIG. 11

$$I = \frac{I_1 E}{E - E_1} \qquad (4)$$

where I = amperes in main pipe;
I_1 = amperes indicated by ammeter *c* when switch *d* is closed;
E = volts indicated with switch *d* open;
E_1 = volts indicated with switch *d* closed.

EXAMPLE.—In Fig. 11, the current indicated by *c* with *d* closed is 20 amperes and the reading of *e* is 300 millivolts. With *d* open, *e* reads 400 millivolts. How many amperes are flowing in the pipe?

SOLUTION.—In formula 4, $I_1 = 20$, $E = 400$ millivolts $= .4$ volt, $E_1 = 300$ millivolts $= .3$ volt; hence,

$$I = \frac{20 \times .4}{.4 - .3} = 80 \text{ amperes. Ans.}$$

24. Systems Free From Electrolysis.—Systems using the double overhead-trolley or conduit system where the rails do not form the return circuit, are, of course, free from trouble due to electrolysis. Also roads where alternating current is supplied to the cars are exempt because alternating current, even if it does return by way of pipes, is incapable of producing any electrolytic effect.

AUXILIARY EQUIPMENT

25. The part of an electric-railway system that pertains directly to the supply of current for the cars has been taken up, but the rolling stock and car equipment remain to be considered. Before going on to this part of the subject, it may be well to pay some attention to the auxiliary departments of a road. Under this head may be included car houses or car barns, repair shops, etc. These, while not, perhaps, directly connected with the running of the cars, are at the same time an essential part of the road. Their equipment varies greatly on different roads, so that the descriptions can only be very general in character.

THE CAR HOUSE

26. The **car house** or **car barn** is a building used for storing cars that are not in use. It is now customary to provide storage under cover only for those cars that are not in regular commission. Cars that are running regularly are stored outdoors; there is no good reason why a car that is in fit condition to be out all day in all kinds of weather should be put under cover over night, especially when such storage room is expensive and when there is always more or less danger from fire.

Where practicable, the tracks in car barns should be far enough apart to admit of easy passage between them, and the more uniformly the daylight is diffused throughout the building, the better. In some car houses, the storage room is all on one floor; this may be the first or second floor, according as the cars to be stored are out of season or are just temporarily out of use. In other storage houses, two or more floors are used, in which case an elevator must be provided for handling the cars on the upper floors.

Where the cars must be transmitted to and from an upper story by means of an elevator, it is almost always the case that the stripped or out-of-season cars are stored there. As there is no possible chance of saving the cars in time of fire, there is no objection to setting them on horses or barrels; but where the storage tracks are on a level with a street track, the cars should be set on temporary trucks, so that at an alarm of fire they can be run out. Where practicable, every storage track should lead to the street at one end or the other of the car house. In some houses it is the practice to grade the rails down to the street, so that in case of fire it is only necessary to let off the brakes and the cars will run out.

27. For inspection of trucks and motors there should be **pits** about 4 feet 8 inches deep directly under the tracks, no pit to be shorter than any car that may be placed over it. As to the total amount of pit room required per car, it is a very hard matter to fix between narrow limits, as it depends a great deal on how much trouble the equipments give. A safe value, however, based on long experience with almost all conditions of working with several types of motors and trucks, is 1 linear foot of pit room for each car that runs into the depot; though in some modern car barns the allowance is much less than this for the reason that it is now considered best to remove the car bodies from the trucks and work on the motors from above when thorough overhauling is required. Pits are used for ordinary inspection or for light repairs, but when an equipment has to be thoroughly gone

over a much better job can be done by dispensing with pit work altogether. The pits should have cement bottoms and be properly drained. The space between the tracks on the floor level should be boarded, but the underneath space between the pits should be left open.

A couple of shelves and a row of small bins to hold a few of the most commonly used sizes of bolts, nuts, and washers save time and should be placed in each pit.

28. Wiring of Car House.—The wiring of the car house is a simple matter, but its plan depends on the track layout of the house. Every track should have a trolley wire over it. The house trolley wiring, as a whole, should be separated from the main line outside by means of a line circuit-breaker; it must then be connected to the street wires by means of a jumper that passes through a switch placed outside of the building, so that in case of fire the whole house wiring can be disconnected. The wires in the house are supported on barn hangers (see Fig. 12). The hanger is fastened to the house beam by means of lugs *b*, *b*, the trolley wire being fastened to ear *c*; in barns with steel roof trusses, the hanger must be screwed to wooden blocks supported from the iron girders. In some barns, the trolley wire is run in an inverted wooden trough, the hangers being screwed to the bottom of the trough. In such a case, the trough generally catches the wheel if for any reason it leaves the wire; it also serves as an insulated support for the wheel at night and obviates the necessity of tying down the pole where such a rule is in force. Sometimes at short curves under very low structures it is the practice to do away with the trolley wire altogether and replace it with an inverted brass or copper trough, in which the trolley wheel rolls along on its flanges.

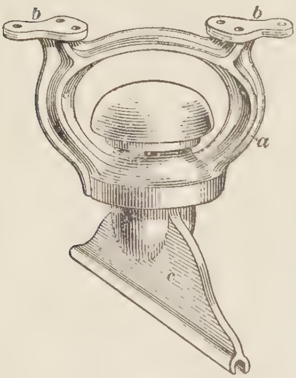


Fig. 12

THE REPAIR SHOP

29. The **repair shop** is the place where all heavy repairs and alterations are made. A well-appointed repair shop should include a machine shop, carpenter shop, mill, blacksmith shop, paint shop, winding room, commutator room, controller room, and a wheel-grinding annex. In the machine shop, all general machine work is done, such as fitting bearings, turning down commutators on the shaft, recutting bolts, etc. In the winding room, fields, armatures, armature coils, etc. are wound, insulated, and baked. In the commutator room, the parts of the commutator are assembled and the finished article tested. In the controller room, controllers, switches, resistances, etc. are repaired, and in the mill, the repair parts for car bodies are made. The shop building should be a substantial fireproof structure and every effort should be made to have good light throughout.

30. The Pit Room and Machine Shop.—The number and length of the pits depend on the nature of the work to be done and the number of cars to be handled. The pit rails should be laid on stringers supported by brick piers, and the space underneath between pits should be left open, so that a man can go from one pit to another without going up on the floor. There should be means provided for raising the car bodies off the trucks quickly and with as little labor as possible. It is common practice to provide car shops with an air compressor and reservoir, the air to be used in blowing the dust out of motors, controllers, etc.; in such a case, the compressor, or air pump, is driven by a motor. The air pump stores the air in a main reservoir that is piped to auxiliary reservoirs situated at the points where the air is to be used. Air has proved to be the best thing for cleaning purposes, and in the several instances where it has been used as a means of operating lifts to raise cars and to handle heavy work around the lathe and boring machines, it has scored an equal success.

31. The Machine Shop.—In laying out a machine shop, two important points must be kept in mind: the machines

must be so disposed as to admit of having a good light thrown on the work and at the same time must take up as little floor space as possible. The number and kind of machines to be installed depend on the class of work to be done. There should be enough machines so that the work may not be held back for want of them, but at the same time there should be no more of the same or similar kinds than can be kept busy.

The machines necessary are about as follows: One lathe to take an axle with the wheels on it; one smaller one to take armatures and bearings; one speed lathe; one metal saw; one large and one small drill press; one boring mill; one planer and shaper; one bolt-cutting machine, with right- and left-hand dies; one milling machine; one wheel press; one axle straightener; emery wheels; one grindstone; one power hack saw; one ratchet drill; one punch press; and one power hammer, usually in the blacksmith shop. On a small road, some of the above might be omitted.

32. The Winding Room.—As good a place as any for a winding room is in a gallery built around the wall above the machine shop, but a great many object to this plan on the ground that all cores to be wound and wires for winding must be elevated to the gallery. This is true; and where there is plenty of room on the ground floor, it is best to do the winding there; but where space is limited, the above location is a good one. The size of the armature room required for a given number of cars depends, of course, on many local conditions. For a road operating 100 cars or over, from 6 to 8 square feet of floor space per car should be sufficient. For a small road, the space required per car would be much larger. Every winding room in which all the processes of winding are carried out and where coils are not bought ready-made, should be equipped with about the following: One machine for putting bands on armatures; one field-winding machine; one armature-coil winding machine with a coil former for each type of armature; one gasoline stove, brick-enclosed, with the tank well removed and

enclosed (gas is better and safer when it can be had) for heating soldering irons; a device for pulling off commutators (the pinions should be removed before the armatures are sent in); racks for holding rolls of insulation; stands for holding armatures in course of winding; one machine for cutting insulation; one machine for pressing coil papers; one coil press for each kind of coil; ample facilities for dipping the coils in varnish or some other compound; racks for holding completed armatures; an oven or its equivalent for baking armatures (it can be either steam-heated or heated with street-car heaters). If the armature coils are dipped in an air-drying compound, no oven is needed, because the armatures themselves and the fields and other coils can be baked by sending a current through them; but if the armature coils are to be dipped in varnish—a much better practice—an oven must be provided, and it might just as well be large enough to bake everything.

The winding room should be provided with substantial patterns of every standard piece of insulation used in the place; one set of these should be hung in a convenient place; a duplicate set should be kept under lock and key, preferably in a fireproof place.

33. The Commutator Room.—The commutator room should be in charge of a good mechanic, and should contain a lathe, a drill press, a milling machine, and an oven for baking commutators. It should be provided with a full line of gauges for the several kinds of mica bodies used and plug gauges for the shaft hole bored in the shell. There should be provided a device for tightening up the nuts without twisting the commutator bars out of line. There must be an adequate supply of assembling rings and the proper wrenches for adjusting them; no emery wheel should be allowed in the commutator room. The most natural and convenient location for the room is next the winding room; it should be enclosed, but should have the best possible light and ventilation.

34. The Controller Room.—There is no particular condition to be fulfilled in selecting a site for the controller

room A location just off the machine shop, where it will be convenient to the machines, is as good as any.

35. The Mill and Carpenter Shop.—The mill is the room in which the wood-working machines are placed and the carpenter shop is where the cars are run in for general body repairs. There is no reason why they should not both be within the same enclosure—the mill at one end and the carpenter shop at the other. The best place for them is between the machine shop, pit room, and paint shop, a line of single or double track running through, so that a car can come in at one end of the building and go out at the other. In the mill there should be a planer, boring machine, lathe, band saw, circular saw, and grindstone.

36. The Paint Shop.—The paint shop should be at the extreme rear of the main shop and should have free access to the street; it should be provided with as many doors on the street side as there are tracks, so that in case of fire the cars can be run out without any shifting or transferring. The paint shop should receive only cars that have been repaired and are ready to run on the road except for the painting. This being the case, each track in the shop should have a trolley wire over it, the whole system of trolley wires being kept cut out by means of a switch except when they are to be used. Under no circumstances should the car bodies be set on horses or barrels in the paint shop; the risk of fire is too great. They should always be on temporary trucks, and where possible, at the head of each line of cars should be a car fully equipped, so that in case of fire they can be coupled together and towed out of danger. Another good plan is to have the tracks down grade out of the house, so that when the brakes are released or the chocks removed from the wheels, the cars will run out by gravity. On account of the great fire risk incidental to the storage of so many inflammable materials, oils, varnishes, etc., there should be an absolutely fireproof wall between the paint room and the rest of the shop, communication between the two shops being only through self-closing fireproof

doors. As a prime precaution against fire, the building should be of brick, with a fireproof roof and a cement floor. The floor should be graded to gratings that lead to the sewer or to a cesspool and the roof should be designed to give the best possible light and ventilation. All inflammable materials should be kept in a small, absolutely fireproof room that will admit barrels, etc., without trucking them the entire length of the paint shop. The question of fire risk in a paint shop is a serious one, for the reason that the shop is generally full of cars that will burn quickly if once started.

37. The Blacksmith Shop.—The blacksmith shop must be located where the coal dust and gases from the forges cannot reach the paint shop. It should contain at least two forges, anvils, and a blower. One forge should be provided with an ordinary bellows all ready to be connected on, in case anything should happen to the blower or to the motor from which it is run. Besides the usual complement of forge tools, there should be a machine hammer, shears, and a drill press.

38. The Grinding Room.—If the brakes on a trolley car are applied too hard or if for any other reason the car skids along the track, flat spots, or **flats**, as they are called, are found on the tread of the wheel. These make the wheels pound on the rails, and unless they are removed by grinding or a new wheel put on, the trouble is liable to go from bad to worse. Most car wheels are of chilled cast iron. In the molding, the tread of the wheel is chilled so that the iron is very hard for a depth of $\frac{3}{8}$ or $\frac{1}{2}$ inch. If the wheel is worn down so that the chilled portion is ground through, there is no use in doing anything further with it, as the iron under the chilled part is too soft to last any length of time. If small flats develop, they can often be removed before they get any worse by taking off the regular brake shoe and putting on a special wheel-truing shoe provided with emery, carborundum, or similar abrasive. Fig. 13 shows one of these shoes; it simply replaces the

regular brake shoe and in the course of a few hours' run the abrasive blocks *a* grind the wheel true. When the flat is a bad one, it is removed by a regular grinder, which is a device for holding a revolving emery wheel against the tread of the wheel to be ground. The wheels may be ground either in place on the car or separate from the car. The car-wheel grinder can, as a rule, be used to greater advantage out at one of the depots, if the wheels are to be ground on the car; this is undoubtedly the best practice, but it is not always followed. Where the wheels are taken out to be ground, there must be extra means provided for driving the axle, whereas, if ground on the car, one of the car motors can do the work. In either case, the car wheels should make from 20 to 40 revolutions per minute, and the speed of the rim of the emery wheels should be about 5,000 feet per minute. Steel-tired wheels are trued up by turning in a lathe.

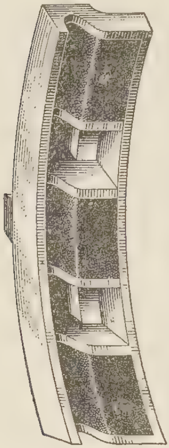


FIG. 13

CAR BODIES AND TRUCKS

CAR BODIES

39. The **car body** constitutes the main part of the car and is mounted either on one or two trucks, depending on its length. Car bodies are made in a large variety of styles, some being open for summer use, others closed, and others a combination of the two. They are made in lengths ranging from 18 or 20 feet to 40 or 50 feet; the larger cars usually have two rows of seats arranged crosswise as in an ordinary steam railway coach.

40. Selection of Car Body.—The selection of the cars for any given road is a matter that requires careful attention. No fixed rules can be laid down to govern the selection of the car body in all cases, because conditions vary and a body

adapted to one place and condition of service might fail entirely to meet the requirements elsewhere. In some places, open cars can be used the year round, while in other sections there are only a few days in the year when closed cars are uncomfortable. The average conditions call for both open and closed cars, and much attention has been paid to the question of devising a car that can be made open in warm weather and closed in cold weather. One result of this has been the so-called *semiconvertible* car, a type which all car manufacturers now make. The nearest approach to a solution of the problem of producing a combination car that is as good in hot as in cold weather is found in the car that is partly open and partly closed. This car has the advantage that it is not only adapted to hot and cold weather, but to rainy weather as well. It has the disadvantage that in no kind of weather does it, as a rule, carry a full load, except during the rush hours, so the power house must carry just so much dead weight over the road. Semiconvertible cars are made in a number of different ways, but the windows are made larger than ordinary. In one style of car both upper and lower window sash can be pushed up into pockets in the roof and held there, thus leaving practically the whole side of the car open. In another type no window sashes are provided at all; the windows are of large heavy glass panes fixed in place but arranged so that they can be removed in summer, thus leaving the side of the car open. Of course, in both cases, entrance must be from the ends, hence these cars cannot load or unload as quickly as a regular open car; at the same time they avoid the necessity of keeping two kinds of cars on hand and have come into very extensive use.

The single-truck four-wheel car is giving way to double-truck eight-wheelers, because a single truck, on account of the limited wheel base, cannot well accommodate a car body over 20 or 22 feet long. The most economical practice from the energy point of view, is to run **trailers**, which are cars similar to motor cars, but lighter and not equipped with motors. On account of the trailer being so light, the ratio

of live weight to total weight carried is very much increased; also, the trailers can be left off when they are not needed. But unfortunately the use of trailers increases the number of accidents and consequent damage suits, and these more than offset the value of the power saved.

The point must often be decided as to whether single-truck or double-truck cars should be purchased for a road. It can be safely said that if there is the least doubt as to which to buy, give the preference to the double-truck car. There is nothing so attractive as a well-built and well-appointed double-truck car. This type of car is easier on the car body, easier on the line work, easier on the track, and last but not least, it is easier on the passengers. Actual statistics show that the introduction of the double-truck car will create travel. Being higher from the rail and longer than the single-truck car, it takes longer to load and to unload passengers, and for this reason is not adapted to local runs, where the travel is heavy and the stops frequent. This, of course, does not apply to open cars, where ingress and egress are just as free as on a single-truck car.

TRUCKS

41. The main requirements of a good truck are that it be easy riding, durable, have few parts, wearing parts easily replaced, and wheels easily changed. The trucks must be entirely self-contained; that is, one framework must include the wheels and axles, the brakes, motors, and driving gear. This in reality constitutes the car, for the car body above is merely a framework to hold and shelter passengers, having none of the vital parts necessary to operation. The fact must not be overlooked, however, that the car body has to stand severe strains on account of the rapid acceleration at starting and an equally heavy strain when the brakes are suddenly applied in stopping; so that this portion of the car must be carefully designed or it will not last long.

42. Classes of Trucks.—Trucks are of two kinds: **single trucks** and **double trucks**; the latter may be

further subdivided into *ordinary double trucks* and *maximum-traction trucks*. A single truck has four wheels, takes a single motor on each axle, and there is one truck to a car; an ordinary double truck has four wheels, all the same size, can take a motor on each axle, and there are two trucks to a car; a maximum-traction truck has two large wheels and two small ones, the idea being to throw most of the weight on the large wheels, which are driven by the motor. The weight on the small wheels is regulated by means of a compression bolt and spring, just enough compression being put on to keep the small wheels on the rail when rounding curves. As a rule, the large wheels take about 70 per cent. and the small ones 30 per cent. of the total weight. Experiment has shown that for a given weight of car, the maximum-traction trucks do not require as large an expenditure of energy as a single truck with a 7-foot wheel base. The single truck, being more rigid, binds more in curves and does not equalize as readily as the maximum-traction truck, with its shorter wheel base. Nevertheless, the maximum-traction truck does not ride as easily as the ordinary truck and is now used comparatively little. The ordinary double truck equipped with a single motor has the disadvantage that the driving power is all on one axle, while the weight is divided between two. The result is a tendency for the driving wheels to spin when called on to do heavy duty, because the traction between the wheel and rail is not great enough. By putting a motor on each axle, making four motors to the car, conditions are much improved.

For large interurban cars, ordinary double trucks are always used, but they must be of heavier construction than for the lighter cars used for city traffic. In many cases, one of the trucks is made especially heavy and both motors placed on it, the other truck being without motors. In some cases, however, where the cars must have a very powerful motor equipment, it has been found advisable to use four motors, one on each axle, because the space is so limited that it is sometimes difficult to develop the necessary power in two motors without overheating.

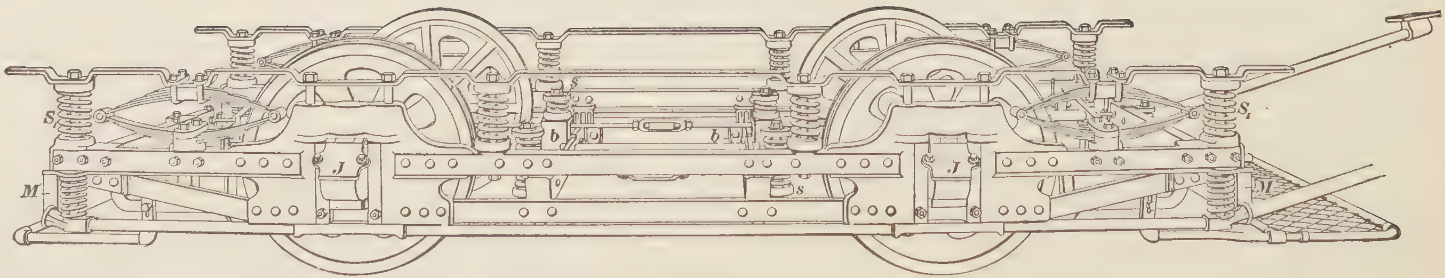


FIG. 14

The car body is rigidly bolted to a single truck by body bolts passing through the car sills and the top rail of the truck's side frame. Double trucks are attached to the car body by means of center bearings and pins, around which the truck turns as a center. Part of the weight is sustained and the car body kept balanced by the **rub plates**, which are circular pieces that engage mates attached to the car body; they should be kept well greased. Cars mounted on double trucks sit higher from the rail than single-truck cars, because the body of the car has to clear the wheels and motors. In open cars the truck wheels have to clear the side steps, so that in some cases two steps must be used.

43. Types of Trucks.—Fig. 14 shows a type of single truck; Fig. 15, an ordinary double truck; Fig. 16, a maximum-traction truck. In Fig. 14, the motors are supported by the suspension bars *b*, *b*, which are in turn carried by the springs *s*, *s* resting on the side frame of the truck. Since it is advisable to support the motor on springs, it is, of course, equally necessary to provide a flexible support for

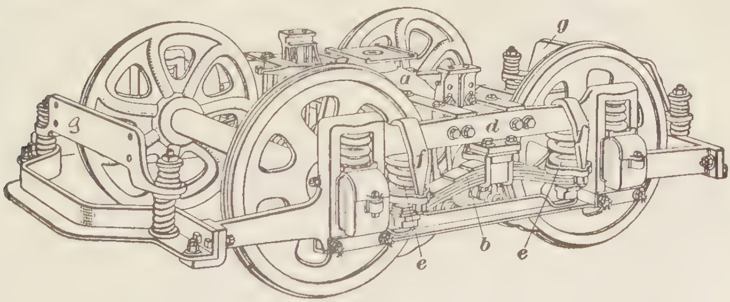


FIG. 15

the truck frame and car body. For short cars, springs placed close to the wheels would be sufficient, although such a construction would have little merit. The reason for providing a longer spring base is to prevent oscillation, which is unpleasant for the passengers and hard on the car body. The oscillation when excessive diminishes the traction on the rising end of the car and causes the wheels to slip. For these reasons, the spring base is extended by

adding extra springs at S_1, S_1. The axle bearings are outside the wheels, to give stability to the car body, the journal-boxes J being free to move vertically through a short distance controlled by a heavy coil spring.

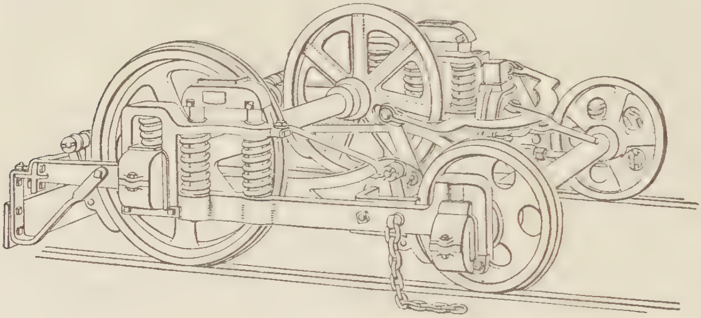


FIG. 16

Fig. 17 shows a larger view of the bearings used on a single-truck car; a is the journal and b the bearing brass, which is on the upper half only, because the thrust is all in one direction. This brass presses against the box casting c,

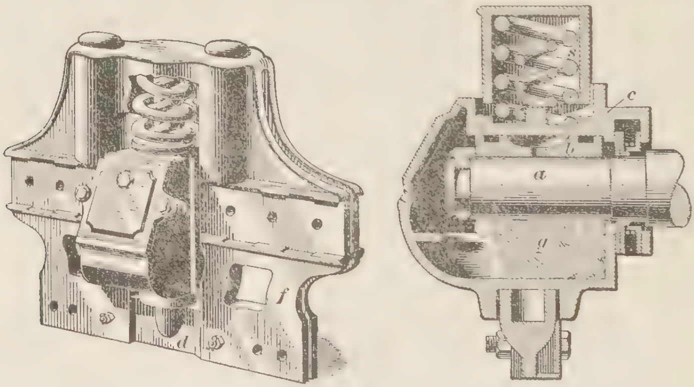


FIG. 17

which in turn bears up against the spiral springs s, that are held in a socket in the frame f. By removing the piece d, the frame can be lifted clear of the axles. The journal is lubricated by means of waste g in the lower part of the casing.

This waste is kept soaked with oil and effects the lubrication in the same manner as on ordinary railway cars. To guard the wheels against obstructions, the **pilots** M, M, Fig. 14, are bolted securely to the frame at a sufficient height from the track to avoid touching the rails.

In Fig. 15, the car body rests on the bolster a, carried by elliptical springs b. The weight resting on springs b is transmitted to the side frame d through equalizing coil springs e and links f. Fig. 18 shows, in detail, the relative arrangement of elliptical spring, equalizing bolt, equalizing spring, equalizing-spring link, and side frame.

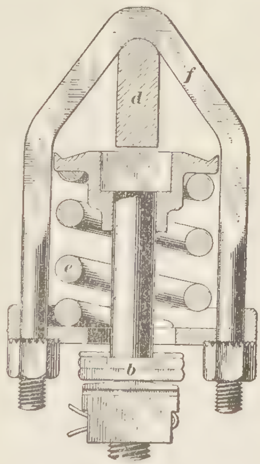


FIG. 18

44. The **wheel base,** that is, the distance between centers of axles on a truck, should be long enough to support the car body without excessive oscillation, but not so long as to make the wheels bind on curves. Any car body that calls for a wheel base of over 8 feet should be provided with double trucks; 7 feet is often given as the limiting wheel base for single-truck cars, but it is practicable to use an 8-foot base unless the curves are of unusually short radius. An 8-foot wheel base will require a much larger power expenditure on curves, but a car is rounding curves only a small part of the time it is in operation, and the increased power consumption is more than made up for by the increase in the size of the car that the longer wheel base makes possible. Excessive length of wheel base not only wears out the rails and wheels, but increases the power required to pull the car around a curve. If it takes a pulling force of 500 pounds to pull an 8-ton car with a 7-foot wheel base around a curve having a radius of 50 feet, it will take a pulling force of only 350 pounds to pull the same car around the same curve on a 4-foot base. To pull the car around a curve of 100 feet radius on a 7-foot

wheel base would require a pull of 255 pounds, and on a 4-foot base, 185 pounds. The difference in the pull required on the two bases on the 100-foot curve is much less than on the 50-foot curve, which goes to show that the greater the radius of the curve, the less difference does it make what the wheel base is. It is evident, then, that in laying out a road, all the curves should be made of as great a radius as possible; and in buying trucks for a road already installed, the radii of existing curves should be considered. With double-truck cars the wheel base may be anywhere from 4 to 7 feet. The 4-foot base would only be used where the curves are very short, the ordinary base for such trucks being 6 feet. For very heavy interurban traffic, a $6\frac{1}{2}$-foot or 7-foot wheel base is frequently necessary to allow room enough for the motors when hung between the axles.

To enable cars to round curves with the least effort and to save the rails and flanges, guard-rail flanges at curves should be kept clean and well greased. Other points to be considered are in regard to the treads and flanges of the wheels; on them depends very much the ease with which a car will take a curve. The treads should not be so wide that they run on the paving outside of the track, and the shape, depth, and width of the wheel flange should be governed by the shape, depth, and width of the rail groove.

45. Wheels used on electric cars vary from 30 inches to 36 inches in diameter; on ordinary street cars, the diameters are usually from 30 to 33 inches. For heavy work it is necessary to use wheels somewhat larger so as to give more clearance for the motors; therefore, diameters of 33 to 36 inches are quite common.

For light cars operating at low speed, cast-iron wheels with chilled treads are used. However, the ordinary chilled wheel is not strong enough for high-speed interurban work, and even for heavy city traffic at low speed it is giving place to the steel-tired wheel, which is provided with a tire made of rolled open-hearth steel. This type of wheel has long been used on steam roads for locomotives and passenger

coaches, but until the advent of heavy electric traction its use on electric roads was limited, owing chiefly to the high cost. The tire can be fastened to the cast-iron center by bolts, or retaining rings, but the usual method in wheels for electric cars is to fuse or cast-weld the tire to the center. The tire is heated, placed in the mold, and the iron center poured; the melted iron fuses the tire and a perfect joint

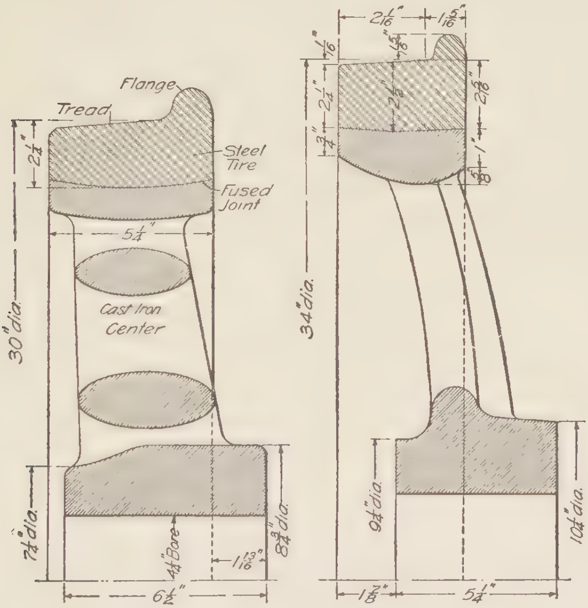


FIG. 19

between the two results. The main advantages of steel-tired wheels that compensate for their high cost as compared with chilled cast-iron wheels are: (*a*) Greater strength and security; these wheels are not likely to fly to pieces no matter how high the speed may be or how severe the strains due to rough track or very cold weather. (*b*) They are not nearly so liable to develop flat spots. (*c*) They are not so liable to slip, since the wrought steel tire has, with the steel rail, a much higher coefficient of friction than a chilled

cast-iron wheel; this reduces slippage and trouble due to flat spots; the action of the brakes is also much more effective. (*d*) They avoid trouble due to chipped or broken flanges. (*e*) The rim can be made thick, so that the wheel will wear a long time before becoming useless; with chilled wheels, the depth of chilled iron is limited.

Fig. 19 shows sections of two fused steel-tired wheels; (*a*) is a 30-inch wheel used on trail cars for an elevated road; (*b*) is a 34-inch wheel for an interurban road. The weight of (*a*) is 650 pounds, and of (*b*) 688 pounds.

METHOD OF SUSPENDING MOTORS ON TRUCK

46. In practically all cases, the motors on an electric car drive the axles through single reduction spur gearing, a pinion on the armature shaft meshing with a gear fastened to the axle. Direct-connected motors, i. e., motors having the armature mounted on the axle, have been tried, but have

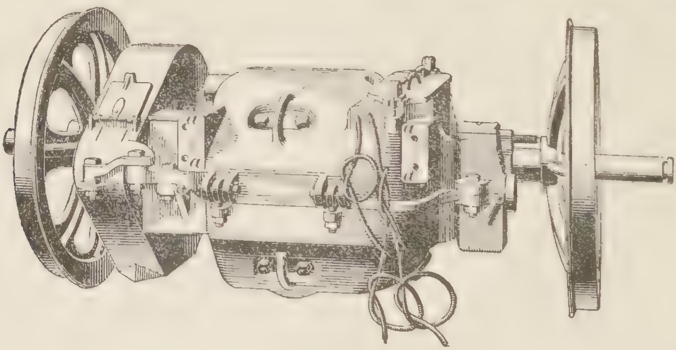


FIG. 20

never proved a success except in some special types of electric locomotive where the motors are of such large size that they can be designed to operate satisfactorily at the low speed necessitated by direct connection.

47. Figs. 20 and 21 show the ordinary *nose suspension*, which is by far the most common method of suspending railway motors. Fig. 20 shows a G. E. (General Electric) 52

motor mounted on the wheels; the axle passes through the axle bearings at the rear of the motor and the front is supported by a suspension bar bolted to the motor at *a a*, *a a* and resting on springs carried by the side frames of the truck. In Fig. 21, the axle *a* passes through the axle bearings *b*, *b* and the motor is prevented from shifting along the

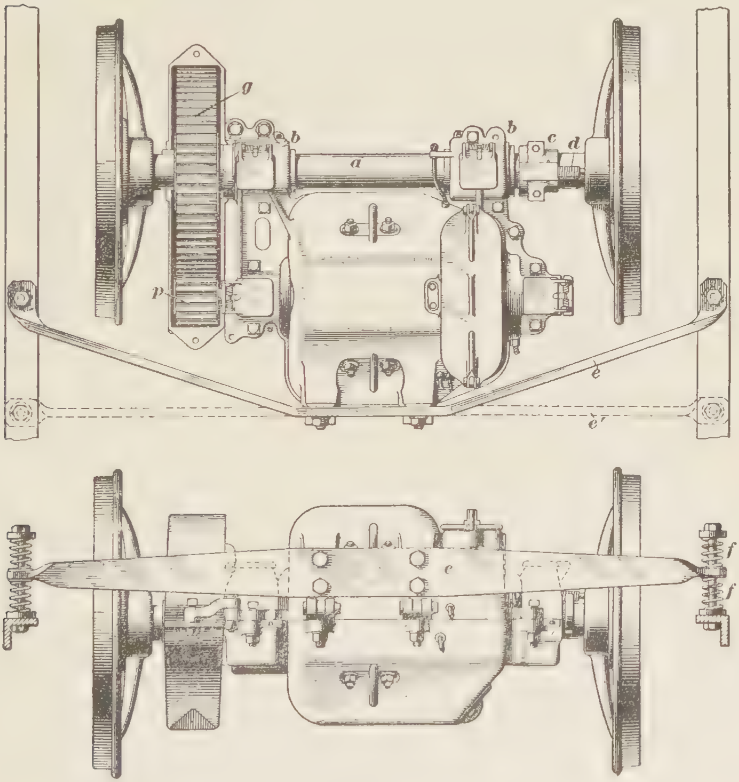


FIG. 21

axle on the one hand by gear *g* and on the other by collar *c*, the location of which can be adjusted by screw *d*. This is a comparatively small motor, and it does not take up all the space between the wheel hubs; with large motors, the space between hubs is often completely filled and no collar is

necessary. Instead of a split collar *c* with a screw adjustment, it is now common practice to use a plain solid collar pressed on to the shaft in the same way as the wheels; it is cheaper than the collar shown in Fig. 21 and there is no possibility of its working loose. The suspension bar may be straight, as shown at *e'*, or bent, as at *e*, but in either case it is supported by springs *f*, *f* carried on the side frames of the truck. In Fig. 15, *g*, *g* show the arrangement of suspension bars for a double truck where the motors are hung outside the axles. For double-truck cars used in city service, the wheel base is frequently not large enough to allow hanging the motors inside the axles, but for large interurban cars where the wheel base is from 6 to 7 feet there is enough room between the axles and bolster to take the motors and they are therefore placed inside the axles, thus making a much more compact arrangement.

No matter what kind of suspension is used, the object is to provide a flexible support for the motor so as to cushion the pounding effect and allow a certain freedom for up and down movement as the car passes over irregularities in the track.

48. Fig. 22 shows a G. E. 74 motor, with nose suspension, mounted on 33-inch wheels. This is a rather large motor (65 horsepower) and takes up all the space between wheel hubs; an axle collar is therefore unnecessary. This motor is designed to be worked on from above rather than from a pit and the upper half of the field frame can be removed and the armature taken out from above without disturbing the lower half of the motor. The suspension bar is therefore bolted to the lower half of the motor instead of the upper half, as shown in Fig. 21, which represents the older arrangement.

49. Westinghouse Cradle Suspension.—Fig. 23 shows a method of suspension used considerably with Westinghouse motors in which the motor is supported by a cradle or frame *A A*. The front of the cradle is supported by a cross-bar that rests on the truck side frames, and the back

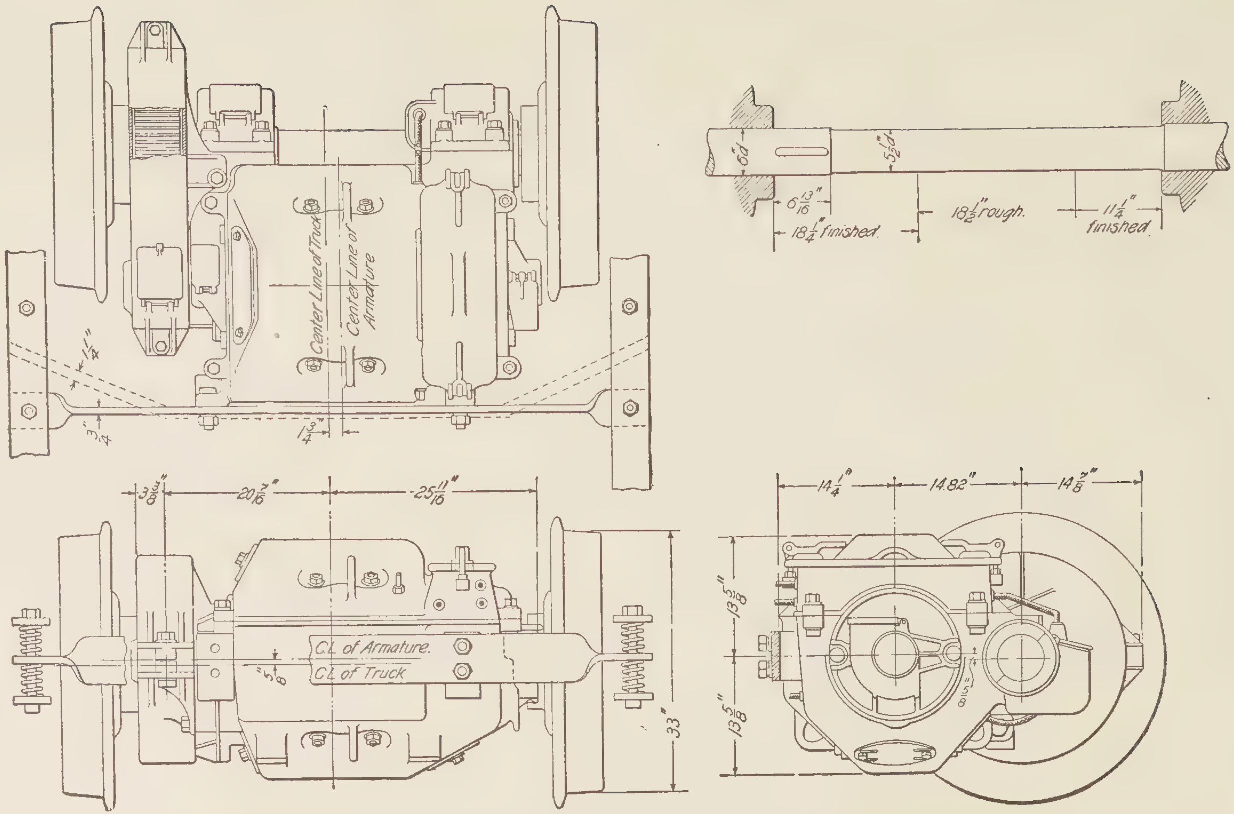

Center Line of Truck
Center Line of Armature
C.L. of Armature.
C.L. of Truck
6"d
5 1/2"d
6 13/16"
18 1/4" finished.
18 1/2" rough.
11 1/4" finished.
3 3/8"
20 7/16"
25 11/16"
33"
14 1/4"
14.82"
14 7/8"
13 5/8"
13 5/8"

Fig. 22

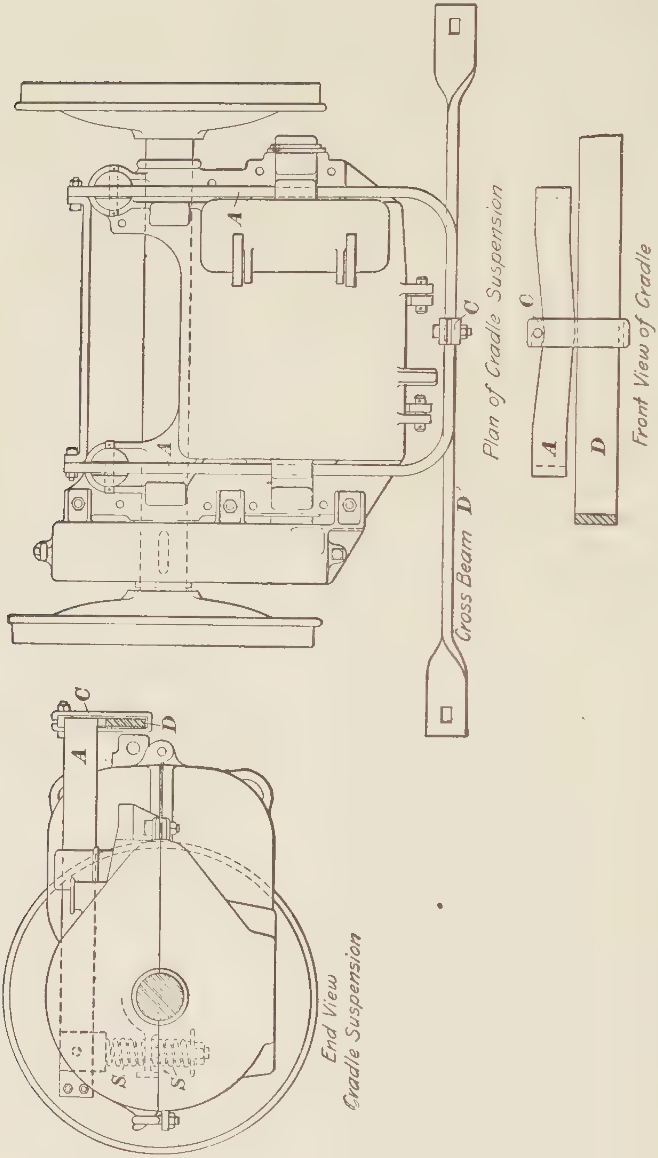

Plan of Cradle Suspension
Cross Beam D'
Front View of Cradle
End View
Cradle Suspension
A
C
D
S
S'

FIG. 23

by means of springs S, S' that bear against lugs cast on the same arm that carries the axle bearings. The sides of the cradle pass through lugs on the ends of the motor and the whole motor is free to move up and down through a limited range, the movements being cushioned by springs S, S' and those placed between the ends of the cross-beam and the truck side frame.

MOTORS AND CONTROLLERS

STREET-RAILWAY MOTORS

INTRODUCTION

1. Street-railway motors have to meet several conditions not imposed on motors used for stationary work. Their design is limited to a large extent by the fact that they must be placed wholly beneath the car. They must be dust-proof and waterproof, because they may have to run through all kinds of dirt and water, and must be arranged so that they can be readily suspended from the car axle. Railway motors must be substantial in every particular, because they are called on to stand harder usage than almost any other kind of electrical machinery.

Practically all railway motors, whether for direct or alternating current, are of the series-wound type. For this service, a motor must be able to give a strong starting effort and an increasing torque with decreasing speed. Shunt-wound motors run at a nearly constant speed regardless of load, and a car equipped with them would ascend grades at about the same speed that it would run on the level; whereas, a series-wound motor, when the load is increased, will decrease its speed automatically. Variable speed is essential for railway operation and the shunt-wound motor is a constant-speed machine; hence, it has never been used, to any extent, for this class of work. Another great advantage of the series motor is that it can be made to exert a very strong starting effort. All current that flows through the armature also flows through the field, and a very strong field is thus obtained at starting. With a shunt motor, the current in the

field is fixed by the resistance of the winding and the line E. M. F.; consequently, the field cannot be strengthened when an especially strong torque is desired. Another incidental advantage of the series motor is that the field coils consist of a few turns of coarse wire and are much more substantial and cheaper to wind than fine-wire shunt coils.

2. Speed Reduction.—It has not been found practicable or economical to drive ordinary electric cars by means of motors having their armatures mounted directly on the axles, though such motors may be used to advantage in special cases when they are of large size, as, for example, on heavy, high-speed, electric locomotives. For ordinary work, motors are always geared to the axle; a pinion on the armature shaft engages with a gear keyed to the axle, both gears being covered by a gear-case that contains a quantity of heavy oil. The reduction in speed depends on the relative number of teeth in the two gears; the smaller the pinion, as compared with the gear, the greater will be the reduction.

The **gear-ratio** of an equipment will here be understood as the ratio of the number of teeth in the gear to the number in the pinion; this is the more usual way of expressing it, though it is sometimes given as the ratio of the number of teeth in pinion to the number in gear. The pinion has, in nearly every case, a number of teeth considerably smaller than that in the gear, so that there is little cause for confusion no matter which way the ratio is stated. If, then, a motor has 14 teeth in the pinion and 68 in the gear, the gear-ratio is $\frac{68}{14} = 4.86$ and the motor armature runs 4.86 times as fast as the axle. Table I gives the speed of car axles, in revolutions per minute, for different car speeds and diameters of wheels. By multiplying the revolutions given in the table by the gear-ratio in any given case, the speed of the motor armature is obtained.

EXAMPLE.—A car is mounted on 33-inch wheels and runs at a speed of 20 miles per hour; how many revolutions per minute do the motor armatures make if there are 65 teeth in the axle gear and 15 in the pinion?

Solution.—The speed of the car axle, Table I, for 33-in. wheels and a speed of 20 mi. per hr., is 203.7 rev. per min. The gear has 65 teeth and the pinion 15, hence the gear-ratio is $\frac{65}{15} = 4.33$. The speed of the armature is, therefore, $203.7 \times 4.33 = 882$ rev. per min., approximately. Ans.

TABLE I

REVOLUTIONS OF CAR AXLE CORRESPONDING TO VARIOUS CAR SPEEDS

Speed of Car Miles per Hour	Speed of Car Feet per Minute	Speed of Car Axles (Revolutions per Minute)						
		30-Inch Wheels	31-Inch Wheels	32-Inch Wheels	33-Inch Wheels	34-Inch Wheels	35-Inch Wheels	36-Inch Wheels
6	528	67.2	65.0	63.0	61.1	59.3	57.6	56.1
8	704	89.6	86.7	84.0	81.5	79.1	76.8	74.7
10	880	112.0	108.4	105.0	101.8	98.9	96.1	93.4
12	1,056	134.4	130.0	126.0	122.2	118.6	115.2	112.1
14	1,232	156.9	151.7	147.0	142.6	138.4	134.5	130.7
16	1,408	179.2	173.4	168.0	163.0	158.2	153.6	149.4
18	1,584	201.7	195.1	189.0	183.4	178.0	172.9	168.1
20	1,760	224.0	216.8	210.0	203.7	197.8	192.1	186.8
22	1,936	246.5	238.4	231.0	224.1	217.5	211.3	205.5
24	2,112	268.8	260.0	252.0	244.4	237.3	230.4	224.2
26	2,288	291.3	281.8	273.0	264.8	257.1	249.7	242.9
28	2,464	313.8	303.4	294.0	285.2	276.8	268.9	261.4
30	2,640	336.1	325.1	315.0	305.6	296.6	288.2	280.2
32	2,816	358.4	346.8	336.0	326.0	316.4	307.4	298.8
34	2,992	380.9	368.4	357.0	346.3	336.2	326.6	317.6
36	3,168	403.4	390.2	378.0	366.7	356.0	345.8	336.2
38	3,344	425.8	411.8	399.0	387.1	375.7	365.0	354.9
40	3,520	448.0	433.6	420.0	407.4	395.6	384.2	373.6
42	3,696	470.6	455.2	441.0	427.8	415.3	403.5	392.3
44	3,872	493.0	476.8	462.0	448.1	435.1	422.6	411.0
46	4,048	515.4	498.5	483.0	468.5	454.8	441.9	429.7
48	4,224	537.6	520.0	504.0	488.8	474.6	461.1	448.4
50	4,400	560.2	541.8	525.0	509.2	494.4	480.3	467.0

3. Various gear-ratios are used in practice, depending on the size of the motor and the speed at which the cars must run. Usually, the axle gear has from two to five times as many teeth as the pinion, the first value being found only on heavy high-speed cars. For ordinary city street cars, the

gear will usually have from four to five times as many teeth as the pinion. Involute teeth are used and the diametral pitch for ordinary street-car gears is three; i. e., there are three teeth for each inch diameter of the pitch circle. For heavy traction work, gears having a diametral pitch of two and one-half are employed in many cases. The distance between gear-centers for a given motor is fixed, hence the sum of the circumferences of the two pitch circles is fixed and any increase in the number of teeth in one gear must be accompanied by a corresponding decrease in the other; the sum of the number of teeth in the two gears must be constant. For example, suppose that a motor has a 15-tooth pinion meshing with a 65-tooth gear; if the speed of the car is to be reduced by using a 14-tooth pinion, a 66-tooth gear must be used. No matter what combination of gear and pinion is used, the total number of teeth must be 80, otherwise with the given distance between centers, the gears will not mesh properly.

SELECTION OF MOTORS

4. The selection of the type of motor for a given service is a subject that cannot be given too careful consideration. If the motors are not powerful enough, the cars will not be able to maintain the required schedule; or if forced to do so, there will be a large number of breakdowns and the bill for repairs will be heavy to say nothing of the loss due to interference with the traffic. On the other hand, if motors much larger than required are installed, an unnecessary outlay of capital is entailed and the road is burdened with an expense that might have been avoided. Again, unnecessarily large and heavy motors involve a waste of power, because of the extra weight that must be propelled and also, to some extent, because of the greater iron losses in the larger motor. Finally, excess of weight means unnecessary pounding of joints and deterioration of track.

In order to secure the best results, the selection can be made only after a careful consideration of all local conditions

affecting the power necessary to propel the cars. It is better to have the motors a little too large than too small, but at the same time it is not economical, from either the standpoint of investment or power consumption, to install motors much larger than are necessary.

RATING OF MOTORS

5. There has been much discussion as to the manner in which the output of street-railway motors should be expressed. The load that a motor can carry is limited by the heating effect, and it has become customary to rate motors according to the output, or brake horsepower, that they will deliver continuously for a period of 1 hour with a limiting rise in temperature of 75° C. above surrounding air at 25° C. For example, according to this rating, a 150-horsepower railway motor is one that will deliver 150 horsepower for 1 hour with a rise in temperature not exceeding 75° C. above the temperature of surrounding air at 25° C. This method of rating is not wholly satisfactory, but it is useful in giving a comparative idea as to the capacities of motors and it is also of value in that it shows the performance of the motor as regards sparking and general behavior of the commutator and brushes. Moreover, it is a difficult matter to give a motor a shop test that exactly duplicates its service conditions; whereas, the 1-hour test at full load is easily applied.

6. Service Capacity.—In order to express more closely the output of which motors are capable in regular service, they are now very generally rated by the current that they can carry continuously, without overheating, under conditions that duplicate, as far as possible, those met with in regular service.

The heating of a motor is due to the $I^2 R$ loss in the windings and the core loss in the armature. The copper losses depend on the current, which, on a car in regular operation, is continually changing in amount. The current is large at starting, but rapidly falls off as speed is attained; while at times the car may coast along without any current. The

heating effect of the current is proportional to the square of the current at any given instant and the heating effect of the variable current will be the same as a steady current equal in amount to the square root of the mean square of the various values of the variable current. If then a motor is to operate without overheating, this square-root-of-mean-square, or effective, value must not exceed that which the motor could carry continuously and not for 1 hour only. It should be noted that the effective current is not the same as the average current taken by the car. If a test be made on a car during an extended run, the current can be recorded by means of a recording ampere meter or the total quantity of electricity applied can be measured by means of an ampere-hour meter. The number of ampere-hours divided by the number of hours during the test run gives the average value of the current. The heating effect is, however, proportional to the effective value and not to the average value, and the effective value can be found by taking the square of the current at sufficiently close intervals, finding the average value of these squares and extracting the square root of the average so found. In fact, the terms average and effective have here the same meanings that were explained in connection with alternating currents. The effective value of the current must be obtained from the current curve, because this curve is very irregular and does not follow any fixed law. There is no fixed relation between the effective value and the average value, though for a given class of service the relation can be determined approximately. The effective value may be anywhere from 25 to 100 per cent. greater than the average value, depending on the kind of service; for ordinary street-car service it will be about 35 per cent. greater. If, therefore, a number of trial runs showed that each motor of a car had to carry an average current of 30 amperes, the effective current would be approximately $30 + .35 \times 30 = 40.5$ amperes and the motors selected for the work should be able to carry continuously a steady current of this amount. On the other hand, a motor rated as being able to carry a steady current of, say, 30 amperes, should

not be made to carry an average current of more than $\frac{30}{1.35} = 22.2$ amperes in regular service. These values are, of course, only approximate, because the variable character of the service, number of stops, grades, curves, etc., make it practically impossible to give any relation between average and effective current that will be applicable to all classes of service.

7. In testing a motor to determine its service capacity, the voltage applied should be the average voltage on which the motor operates when used on a car. The core loss increases with the voltage, because the higher the voltage the higher is the speed of the armature and the more rapid are the reversals of the magnetism in the core. When a motor is in operation on a 500-volt circuit, the average voltage applied is not 500 volts but is usually considerably less. When the car is at a standstill, no pressure is applied; and when being started a part of the applied pressure is taken up in the starting resistance. Again, as explained under the heading Speed Control, there are times when two motors are connected in series across the line, under which condition the pressure applied to each motor is only one-half the line voltage, or about 250 volts. For these reasons, the average pressure applied to the motors in ordinary city traffic will seldom exceed 300 volts, and even in suburban traffic, where there are fewer stops, it will not often exceed 400 volts. In giving the rating of a motor in terms of the current that it can carry continuously, it is necessary, therefore, to state also the average voltage at which the current is supplied; in many cases, two current ratings are given, one at an average pressure of 300 volts and the other at 400 volts.

MOTOR CHARACTERISTICS

8. In determining the suitability of a motor for a given class of service, it is necessary to have information showing the performance of the motor. This is obtained from tests

made by the manufacturers, and is usually given in the form of curves, known as **motor characteristics**, that show the relation between the current, speed, tractive effort, brake horsepower, and heating effect. Fig. 1 is a set of these curves for a No. 68 Westinghouse motor.

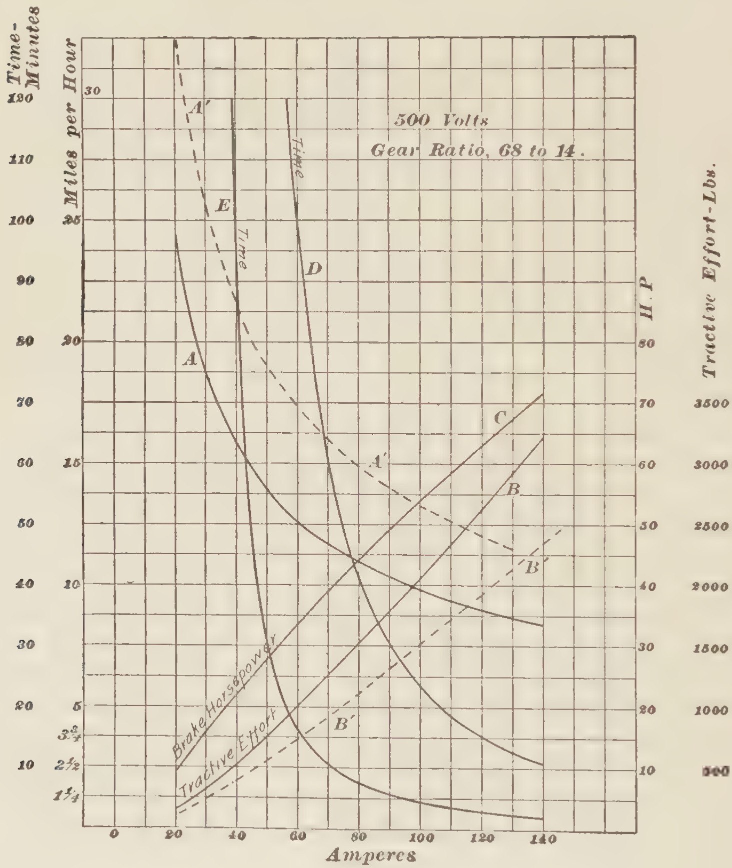


FIG. 1

9. Speed Characteristic.—The curves, Fig. 1, are drawn for a constant applied E. M. F. of 500 volts, which is the normal voltage at which the motor is intended to operate. As the current increases the speed decreases,

because of the increase in field strength, and the speed of the car, therefore, decreases as shown by the speed curve A. The speed of the car corresponding to any given current depends on the gear-ratio and the diameter of the wheels, hence both of these must be stated in connection with the curves. In this case, there are 14 teeth in the motor pinion and 68 in the axle gear, and the wheels are 33 inches in diameter. A curve showing the relation between armature speed and current would have the same general shape as A.

10. Effect of Increase in Voltage.—An increase in voltage increases the speed in almost direct proportion. For example, in Fig. 1, the speed corresponding to 60 amperes is 12.5 miles per hour; if the pressure were increased from 500 volts to 600 volts, the speed corresponding to the same current would be approximately $12.5 \times \frac{600}{500} = 15$ miles per hour.

11. Tractive Effort Characteristic.—Curve B shows the relation between current and tractive effort. This, of course, refers to the effort exerted by a single motor and gives the total force at the two wheels on which the motor is mounted; thus, for a current of 50 amperes, the total tractive effort at the rail head is 750 pounds, or 375 pounds at each driving wheel. The torque of a series motor increases rapidly with the current; hence, the tractive effort also increases, curve B having the same general shape as one showing the relation between motor torque and current.

12. Relation Between Motor Torque, Gear-Ratio, Speed, and Tractive Effort.—Fig. 2 shows the forces acting on a car wheel, gear, and pinion; r is the radius of the pitch circle of the pinion, r' that of the gear, and r'' that of the car wheel. When current flows through the motor, the torque or twisting action that is exerted on the armature and pinion depends on the value of the current and the electrical design of the motor. The motor torque will be $F' r$, when F' is the force exerted at the pitch circle; torque is always expressed as force $\times$ radius and

must not be confused with the force F'. For a given torque, F' will vary with the radius of the pinion, but the product $F' r$ will remain constant, because if r is increased or decreased F' will be decreased or increased by a corresponding amount. The torque exerted on the axle is $F' r'$ and is greater than $F' r$ because the radius, or lever arm r', is greater than r. Since the number of teeth in a gear is proportional to its diameter or radius $\frac{r}{r'} = \frac{n}{n'}$, or $r' = r\frac{n'}{n}$, where n is the number of teeth in the pinion and n' the num-

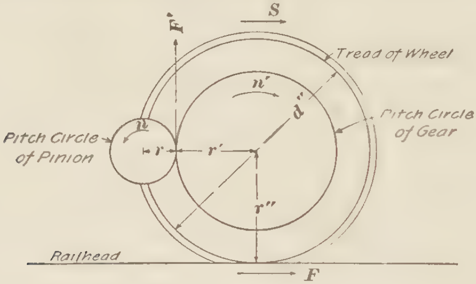


FIG. 2

ber of teeth in the gear. The torque exerted on the axle is $F' r'$, or $F' \times r\frac{n'}{n} = F' r \times \frac{n'}{n}$. But $F' r$ is the motor torque, hence the torque exerted on the axle is equal to the motor torque multiplied by the number of teeth in the gear and divided by the number of teeth in the pinion, or, in other words, the torque exerted on the drivers is equal to the motor torque multiplied by the gear-ratio.

The total tractive effort F, Fig. 2, exerted at the rail head by both wheels, is equal to the torque $F' r'$ divided by the wheel radius r''. Thus, $F = \frac{F' r'}{r''} = F' \frac{r\frac{n'}{n}}{r''} = \frac{F' r}{r''} \times \frac{n'}{n}$. If $F' r$ is expressed in pound-feet, and, if instead of r'', the wheel diameter d'' is used, the formula becomes

$$F = \frac{24\, F' r}{d''} \times \frac{n'}{n} \qquad (1)$$

where F = total tractive force, in pounds per motor;
$F' r$ = motor torque, in pound-feet;
d'' = diameter of wheel, in inches;
n' = number of teeth, in gear;
n = number of teeth, in pinion.

EXAMPLE.—A car is equipped with motors, having 15-tooth pinions and 65-tooth gears, mounted on 33-inch wheels. What will be the tractive effort per motor when the current is such as to give a motor torque of 300 pound-feet?

SOLUTION.—In formula **1**, $F' r = 300$, $d'' = 33$, $n' = 65$, $n = 15$. Hence,

$$F = \frac{24 \times 300}{33} \times \frac{65}{15} = 945 \text{ lb., approximately. Ans.}$$

13. The number of feet traveled per minute by a car is $\frac{3.1416\, d'' s'}{12}$, where d'' is the wheel diameter, in inches, and s' the axle speed, in revolutions per minute. Since 1 mile per hour is equivalent to 88 feet per minute, the speed, S, of the car, in miles per hour, is $S = \frac{3.1416\, d'' s'}{12 \times 88}$ or

$$S = \frac{d'' s'}{336.1} \qquad \textbf{(2)}$$

14. Effect on Speed of Change in Gear-Ratio.—In Fig. 1, the curves of tractive effort and speed are drawn for a gear-ratio of 68 to 14 and for 33-inch wheels. Assuming that the wheel diameter remains unchanged, let us see what change will be made by substituting gears having a ratio of 64 to 18. The ratio is thus decreased from $\frac{68}{14} = 4.86$ to $\frac{64}{18} = 3.56$. From formula **2**, the car speed is $S = \frac{d'' s'}{336.1}$. But s', the speed of the axle, is equal to $\frac{s}{\frac{n'}{n}}$, where s is the motor speed and $\frac{n'}{n}$ the gear-ratio; hence, $S = \frac{d'' s}{336.1 \frac{n'}{n}}$. For a given current, the speed s of the motor has a certain fixed

value and if $\frac{n'}{n}$ is made smaller, i. e., if the number of teeth in the gear is decreased and the number in the pinion correspondingly increased, it follows that, for the given current, the speed S of the car will be increased. The speed corresponding to the new gear-ratio will be equal to the speed at the original ratio multiplied by the original ratio and divided by the changed ratio. In this case, the original ratio is $\frac{68}{14} = 4.86$ and the changed ratio $\frac{64}{18} = 3.56$. Taking a current of, say, 50 amperes, the speed with the original ratio is, from curve A, about 13.8 miles per hour. With the changed ratio, the speed corresponding to the same current would be $\frac{13.8 \times 4.86}{3.56} = 18.8$ miles per hour. In order, however, to obtain the higher speed with the same current, the weight of car would have to be lessened. By calculating the speed corresponding to various currents, the dotted curve $A' A'$ can be drawn to represent the speed for all current values at the new gear-ratio $\frac{64}{18}$.

15. Effect on Tractive Effort of Change in Gear-Ratio.—A change in gear-ratio affects the tractive effort as well as the speed. For a given current, the power delivered by the motor remains the same, no matter what the speed or tractive effort may be. A decrease in the gear-ratio causes an increase in speed, as indicated by curve $A' A'$; and, as the power curve C remains unaltered, the increased speed corresponding to a given current must be accompanied by a decreased tractive effort. This is also plain from formula **1**, in which any decrease in $\frac{n'}{n}$ makes F smaller. The tractive effort with the changed ratio will therefore be equal to the tractive effort with the original ratio, multiplied by the changed ratio and divided by the original ratio. For example, in Fig. 1, the tractive effort for a current of 50 amperes is 750 pounds with the original ratio; with the

new ratio, the effort will be $\frac{750 \times 3.56}{4.86} = 549$ pounds. By calculating the tractive effort corresponding to a number of different current values, the dotted curve $B' B'$ can be drawn, and curves $A' A'$ and $B' B'$ taken together represent the changed performance due to the change in gear-ratio from $\frac{68}{14}$ to $\frac{64}{18}$.

16. Effect of Change in Wheel Diameter.—With a given gear-ratio and current, a reduction in the wheel diameter causes a corresponding reduction in the speed of the car and vice versa. A decrease in the wheel diameter has the same effect as an increase in the gear-ratio.

17. Effect of Changing Gear-Ratio on a Given Equipment.—It is sometimes important to know the probable change that will be made in the speed of a given car when the gear-ratio is changed, the weight of the car and all other parts of the equipment remaining the same. If the motor characteristics for the original gear-ratio are at hand, the new speed under the changed conditions can be determined approximately, as follows: Calculate two curves, as explained for $A' A'$ and $B' B'$, Fig. 1, to suit the new conditions. From the known weight of car, the tractive effort can be determined approximately, and the speed and current corresponding thereto can be read off from the curves drawn for the new gear-ratio. For example, suppose that curves A and B represent the performance with the original gear-ratio of $\frac{68}{14}$ and that the ratio is changed to $\frac{64}{18}$. Curves $A' A'$ and $B' B'$ then represent the performance under the changed conditions. With the original gearing, a test showed that the car ran at a speed of 13.8 miles per hour on the level and required a current of 50 amperes per motor; the corresponding tractive effort was therefore 750 pounds per motor. With a fixed weight of car the increase in speed does not cause much change in the tractive effort and for low speeds, such as are now under consideration, it may be taken as

750 pounds under the changed conditions. With the changed gear-ratio, a tractive effort of 750 pounds corresponds to a current of about 61 amperes, as shown by curve $B'B'$; and a speed of about 17.25 miles per hour as shown by $A'A'$. The change in gear-ratio has therefore caused an increase in speed, but the increase is not as great as the mere change in gearing would lead one to expect. If the change in gearing alone were considered, the speed would be $\frac{13.8 \times 4.86}{3.56} = 18.8$ miles per hour. However, in order to drive the car at the higher speed, more power must be supplied and the current must therefore increase, thus necessitating an actual decrease in the motor speed. Because of this change in motor speed, with change in current, the final speed of the car must be determined from the characteristic curves for tractive effort and speed, drawn so as to take into account the change in gearing. Since, with a fixed weight of car, an decrease in gear-ratio is accompanied by an increase in current, a point is soon reached beyond which any further change in gearing will cause serious overheating of the motors.

18. High-geared motors take very large currents during the acceleration period unless the controllers are carefully handled, and as a general rule motors should not be geared any higher than is necessary to allow the cars to maintain their schedule with a fair margin; any higher gearing simply causes waste of current and throws an unnecessary load on the equipment. In case the weight of the car is not fixed, a motor can be geared for higher speed without increasing the current. For example, a pair of motors might be taken off a heavy car and placed on a lighter one that requires a smaller tractive effort. If the limiting current is to be the same in each case, the motor torque and the speed of the armature will remain unchanged. Hence, assuming that the wheel diameters are not changed, the smaller tractive force can be obtained by decreasing the gear-ratio and, since the armature speed remains constant, there will be a corresponding increase in the car speed. The power supplied to the

motors remains the same as when they were on the heavier car, the tractive effort being smaller and the speed correspondingly higher.

Therefore, in making changes in the gearing, the weight of car must be kept in mind; if it is not changed in any way, the increased speed may be obtained at the expense of overloading the motors; but if the motors are placed on a lighter car, the increased speed may be secured without any increase in the current or even with smaller current if the second car is very much lighter than the first.

19. Heating Characteristics.—Curve *D*, Fig. 1, shows the time that it takes the temperature of the motor to rise from 25° C. to 75° C. when carrying various currents. Thus, a load of 70 amperes can be carried for 60 minutes if the motor is started at a temperature of 25°, so that on the 1-hour rating this motor will have a capacity of about 38 brake horsepower. However, under ordinary running conditions, the motor is much hotter than 25° C., and the time during which it can carry a given current without rising above 75° C. will be much less than is indicated by curve *D*; the length of time that the motor can carry a given current without overheating is shown approximately by curve *E*, which allows for a rise of 20° C. in the interior of the motor after the motor has attained a temperature of about 55° C. For example, if it is running at 55° C., it will carry a steady current of, say, 50 amperes, or a variable current of which the effective value is 50 amperes, for 30 minutes before reaching 75° C. If the average working temperature were less than 55° C., the currents could be applied for a proportionally longer period without causing a temperature exceeding 75° C.; the current referred to is the current per motor, not the current per car. In making current tests on a motor, the ammeter should be connected in series with the motor and not in series with the trolley. Most cars are equipped with at least two motors operated in series at low speeds, in which case the current in each is the same as the total current, but at high speeds the motors are in parallel

and the current in each is approximately half the total. The average current per motor is, therefore, more than half the total current. Curve *E* is useful in fixing the maximum loads that the motor may take during rush hours or periods of unusually heavy load.

EXAMPLES FOR PRACTICE

1. If a car is mounted on 34-inch wheels and the motors have a gear-ratio of $\frac{68}{16}$, what will be the total tractive effort per motor, when the motor torque is 300 pound-feet? Ans. 900 lb.

2. If the gearing on a car is changed as shown in Fig. 1, and if the tractive effort per motor remains constant, at 1,000 pounds, what will be the change in car speed caused by the change in gearing?
Ans. From $12\frac{1}{2}$ mi. per hr. to about 15.3 mi. per hr.

3. A car is mounted on 33-inch wheels and the motors have a gear-ratio of $\frac{65}{15}$; what will be the speed of the armature, in revolutions per minute, when the car is running 16 miles per hour?
Ans. 706 rev. per min.

TYPES OF MOTORS

20. Direct-current motors, series-wound for 500 to 650 volts, are used on nearly all electric railways. At first, two-pole motors were used but these soon gave place to the four-pole type. Fig. 3 shows some of the field constructions used for well-known motors. (*a*) is the old Thomson-Houston W. P. 50 (waterproof) motor; it has a two-pole field with a single magnetizing coil. (*b*) is the old Edison No. 14, which has a four-pole field with two field coils. (*c*) is the General Electric 800 (G. E. 800) motor field which is similar to the Edison No. 14, but is turned up the other way. (*d*) shows the four-pole magnet frame introduced about 1891 by the Westinghouse Company in their No. 3 motor; it has four poles set on the diagonal, each pole being provided with a field coil. (*e*) shows a field about as used on a modern motor. The frame is of cast steel in order to secure lightness and the pole pieces, instead of being cast with the frame, are built up of sheet-iron stampings bolted

to the frame. This laminated-pole construction reduces heating in the pole pieces and also tends to keep down sparking at the commutator. The constructions indicated in (*a*), (*b*), (*c*), and (*d*) are now obsolete, but many motors in which they are used are still in operation.

Railway-motor armatures are always of the slotted type, the coils being wound on forms and then placed in slots on the core. In the earlier slotted armatures, a large number of slots were used, generally from 87 to 105. This was necessary because, if the slots were made coarse, it was found that they caused the magnetism in the pole pieces to

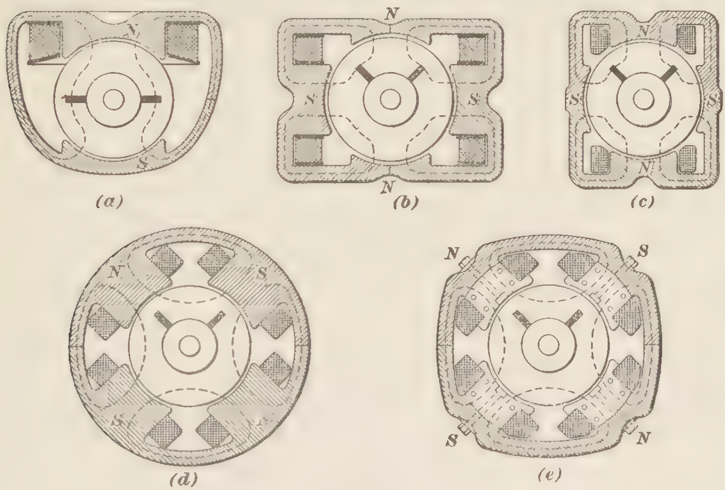


FIG. 3

vary to such an extent that the solid poles would heat considerably. By laminating the poles, it has been found possible to reduce the number of slots to about one-third the number formerly used, thus making them very much larger, cheapening the cost of production, and making the motor operate better generally.

A number of sizes and types of railway motors have been brought out from time to time by the leading manufacturing companies, in order to keep pace with improvements in design or to meet new traffic conditions. Some of the older

motors made by the General Electric Company were designated by the number of pounds tractive effort they could exert with full-load current when provided with standard gearing and mounted on 33-inch wheels. Thus, the G. E. (General Electric) 800 motor can exert a tractive effort of 800 pounds under these conditions; a G. E. 1,000 motor can exert 1,000 pounds; and so on. This method of rating has been abandoned and motors are now designated by arbitrary numbers, as, for example, G. E. 52, G. E. 54, etc. Westinghouse motors are also designated by numbers, as, for example, No. 3, No. 49, No. 56, etc. Table II gives the horsepower

TABLE II

OUTPUT OF RAILWAY MOTORS

Type of Motor	Output in Horsepower (Railway Rating)	Type of Motor	Output in Horsepower (Railway Rating)
G. E. 800	27	G. E. 73	75
G. E. 1,000 . . .	35	G. E. 74	65
G. E. 51B . . .	80	Westinghouse 12A	30
G. E. 52	27	Westinghouse 38B	50
G. E. 54	25	Westinghouse 49 .	35
G. E. 55	160	Westinghouse 50L	150
G. E. 57	50	Westinghouse 56 .	60
G. E. 66	125	Westinghouse 69 .	30
G. E. 67	38	Lorain No. 34 . .	50
G. E. 70	40		

output, based on a run of 1 hour, with a rise in temperature of 75° C. above surrounding air at 25° C., for a number of the motors in most general use. Since all modern railway motors are very similar in their general construction, it will be sufficient to describe here a few typical examples.

G. E. 52 MOTOR

21. Field-Frame Construction.—As an example of a small motor intended for ordinary city traffic where light cars are operated, the **G. E. 52 motor** may be taken. Fig. 4 is a rear view showing the general shape of the field frame,

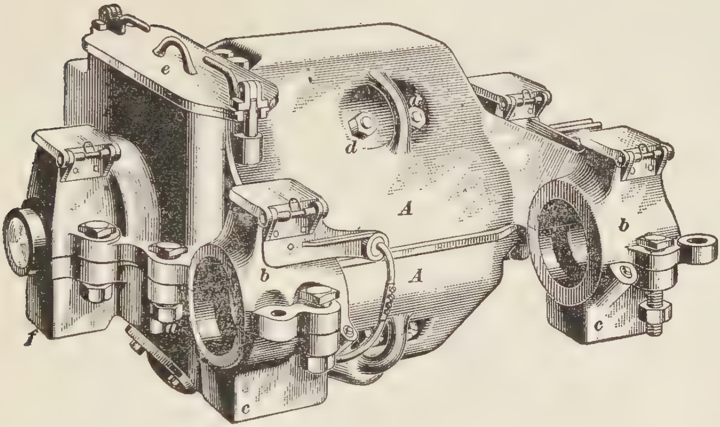


FIG. 4

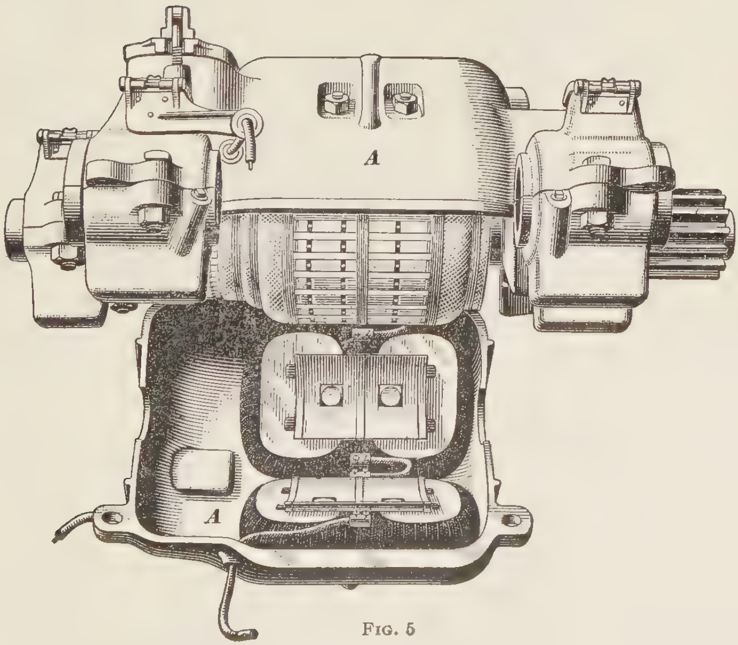


FIG. 5

which, as in all modern motors, is shaped so as to completely enclose the armature, commutator, brushes, and field coils. The field frame is roughly hexagonal in outline and is made in halves, which are held together by bolts. The two arms *b*, *b* extending from the back of the motor receive one-half the axle bearing, which is in the shape of a split bushing. The axle-bearing caps *c*, *c* are provided with grease boxes, and the grease or oil is fed on the axle by means of pieces of felt from underneath as well as from the

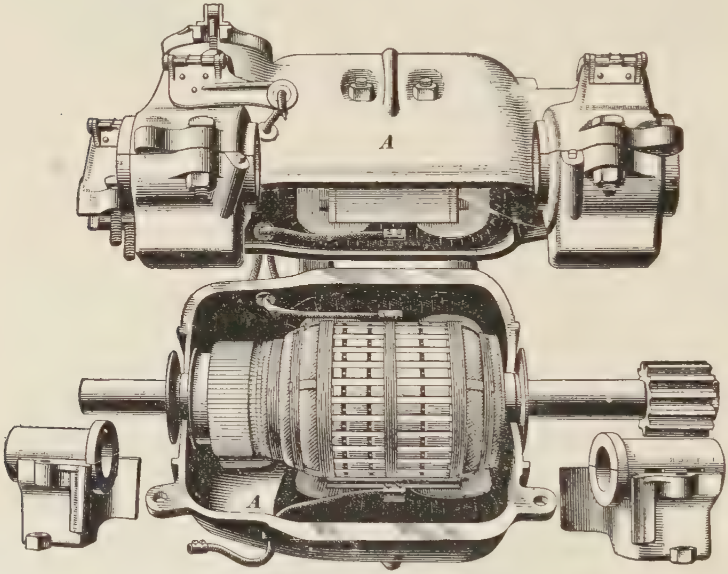


Fig. 6

grease cups on top. The bolts *d*, *d* hold the pole pieces and field coils in place. The removable cover *e* allows access to the commutator and brush holders. The lower armature-bearing caps *f* are separate from the lower half field *A*, and by leaving these caps in position, the lower half field may be swung down, leaving the armature in the upper half, as shown in Fig. 5. By removing the bearing caps, the armature can be lowered with the field, thus leaving the upper field coils and pole pieces exposed, as shown in Fig. 6.

22. Capacity.—The G. E. 52 motor has an output of 27 horsepower, based on a run of 1 hour with a 75° C. rise in temperature. The motor is intended for ordinary street-railway work and is not recommended for the heavier kinds of traffic.

23. Pole Pieces.—The motor has four poles provided with flanged pole pieces that are laminated; the flanges serve to hold the field coils in place, and the laminations not only do away with a great deal of heat in the pole piece, but from the way in which they are built up they produce a magnetic field that does away with much of the sparking at the brushes. The pole pieces are made of iron plates shaped like the full-line part of Fig. 7 (*b*). In building up the pole piece of these plates every other plate is turned end for end with the result that, along the center part of the pole piece, the plates are close together, but on the horns only half of the plates come out on each side, as shown in Fig. 7 (*a*). This plate construction largely prevents sparking at the brushes, because the thinning out of the metal on the horns of the pole pieces produces a *shaded field* or *fringe*. This shaded field provides a fringe that reverses the current in the coil passing under the brush, and hence brings about the change in the direction of the current with but little sparking.

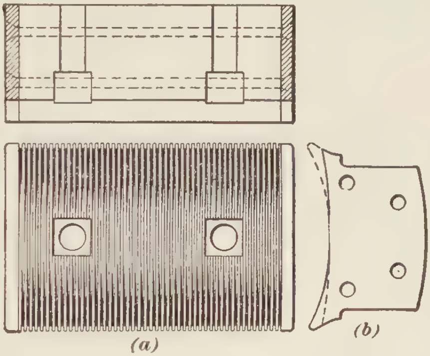


Fig. 7

24. Field Coils.—The field coils are wound on forms, and while the asbestos-covered wire is being wound it is treated with a mixture of chalk and japan and afterwards baked. The coils are heavily insulated with tape and insulating varnish and are given a glazed surface that will readily turn off water and prevent moisture from getting in.

25. Armature.—Fig. 8 shows a half section of the G. E. 52 armature, and its construction is typical of many of the railway-motor armatures now in use. The core is provided with 29 slots. One side of 6 coils goes into each slot, so that there are 87 coils altogether, and the commutator has 87 bars. The coils are bunched in groups of three, one side of one bunch going into the bottom of a slot, and one side of another into the top of the same slot. In Fig. 8, *a a* is the laminated armature core and

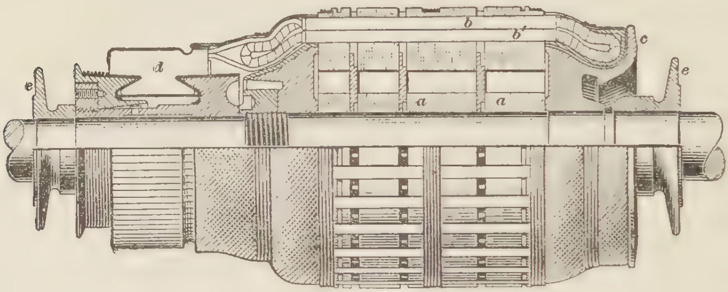


FIG. 8

b, *b′* the upper and lower halves of two coils lying in the same slot. The ends of the coils, where they project from the core, are supported and protected by the end shield *c*. The leads from the coils are connected to the commutator bars *d*, which are mounted as shown. The flanges *e*, *e* are for preventing grease and oil working their way into the armature. The bearings are so arranged that any oil getting on *e*, *e* drops through an opening to the street.

26. Brush Holders.—Railway-motor brush holders are fixed permanently at the neutral point and are not arranged so that they can be shifted, as is the case with many other direct-current machines. The reason for this is twofold: In the first place, the motor has to run in either direction; and in the second place, the variations in load are so sudden that any brush-shifting arrangement is out of the question. The brushes are, however, mounted so that

they can be moved radially toward the center of the commutator as the latter wears away.

Fig. 9 shows the brush holders and brush-holder yoke of the G. E. 52 motor. The yoke *a*, which is made of well-seasoned hardwood treated with insulating material, is bolted to the upper field frame by means of bolts *b*, *b*. The brush holders *h*, *h* are fastened to brass slides on *a* by means of bolts *c*, *c*. All railway motors use carbon brushes; in this case, two brushes $2\frac{1}{4}$ in. $\times$ $1\frac{1}{4}$ in. $\times$ $\frac{1}{2}$ in. are used in each holder.

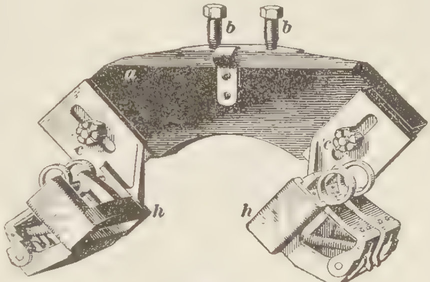


FIG. 9

G. E. 70 MOTOR

27. Figs. 10 and 11 show the G. E. 70 motor, which represents one of the latest types having an output sufficiently large to adapt it for use on suburban cars; its output is 40 horsepower based on the 1-hour rating. The field is made in halves, as shown in Fig. 10, but unlike nearly all the earlier types of motor, the dividing line between the upper half *a* and the lower half *b* is not through the center line of the motor. The upper part lifts off as shown, and dowels *c*, *d* serve to guide it into place when it is lowered into position. The armature bearings are carried in malleable cast-iron frame heads *e*, *f*, Fig. 11, and after these have been unbolted and the top part of the field removed, the whole armature can be lifted out. The object of this design is to make it convenient to work on the motor, from above rather than from a pit underneath, as it is becoming common practice to remove the car bodies from the trucks and work on the motors from above when thorough overhauling is required.

The bearings consist of a bronze lining, or shell, lined with a very thin layer of Babbitt metal that is thoroughly

soldered to the bronze. The Babbitt is so thin that even should the box become hot enough to melt it, the armature will not be lowered sufficiently to rub on the pole pieces. The bronze linings are held securely in the frame heads *e*, *f*, and as the latter have a large bearing surface on the frame and are bolted securely thereto, it is practically impossible for the bearings to get out of line.

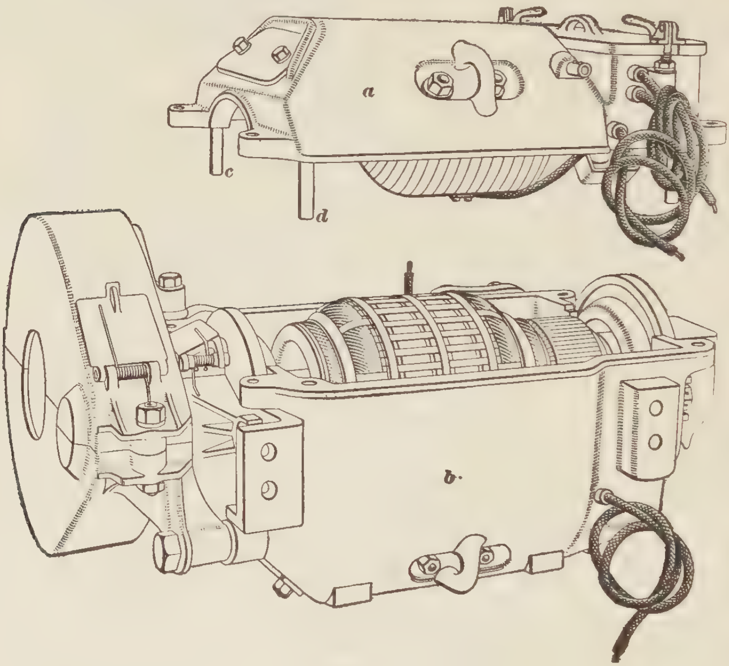


Fig. 10

All bearings are designed for oil lubrication, which is effected in much the same way as on regular car-axle bearings. The linings are in the form of sleeves with openings cut in one side so as to expose the shaft to oily waste that is packed in oil wells, or boxes, cast in the frame heads or in extensions of the brackets that form the axle bearings. The oil boxes are protected by hinged covers held closed by springs. The waste is arranged so that it presses against

the lower part of the shaft and all oil before reaching the shaft must filter through the waste above. If any dirt accidentally gets into the boxes, it is thus prevented from reaching the shaft. This method of lubrication has been found superior to the old method of using grease. Oil deflectors on the armature shaft prevent oil from reaching the armature and commutator, by throwing it into recesses from whence it drops through to the street.

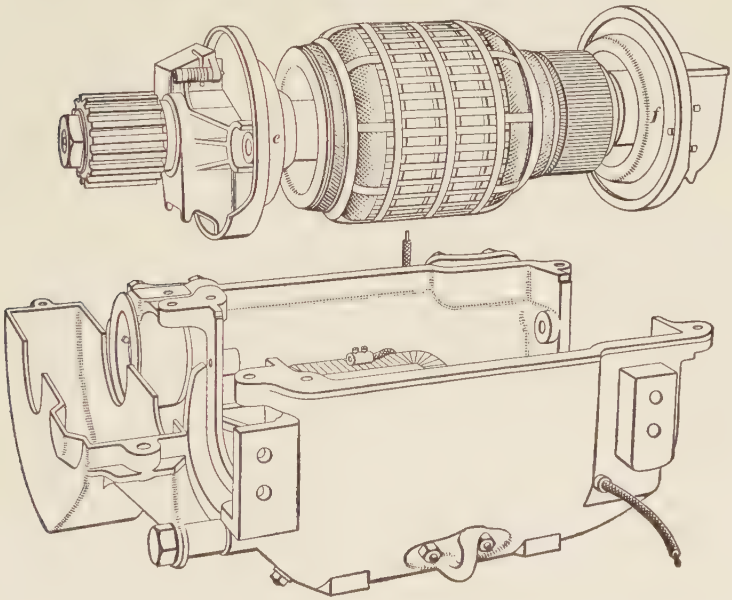


Fig. 11

The four field coils are held in place by the projecting flanges of the laminated pole pieces and, to minimize the chances of abrasion, flanges of steel are placed between the coils and the surfaces with which they come in contact. The coil winding is of the so-called "mummified" type, mica and asbestos being used as insulating materials. Each coil is covered with insulating fabric thoroughly treated with waterproof compound.

G. E. 69 MOTOR

28. This motor, Fig. 12, is of 200-horsepower capacity and represents one of the most powerful types used on elevated and underground roads. Its field frame *a* is of the *box type*, so called because it is cast in one piece, and is

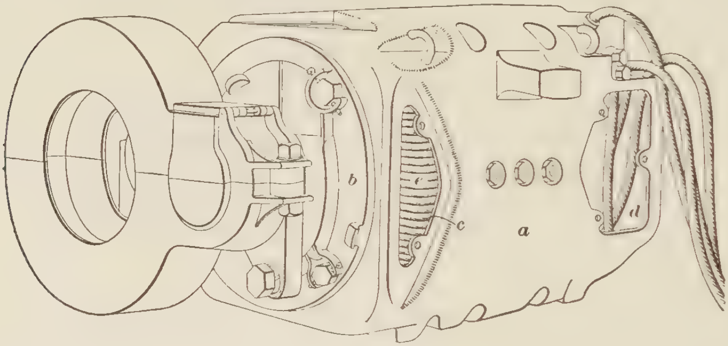


FIG. 12

approximately cubical in outline. The bearings are carried in frame heads, one of which is shown at *b*, in the same way as for the G. E. 70 motor. The heads project within the motor, thus reducing the distance between centers of bear-

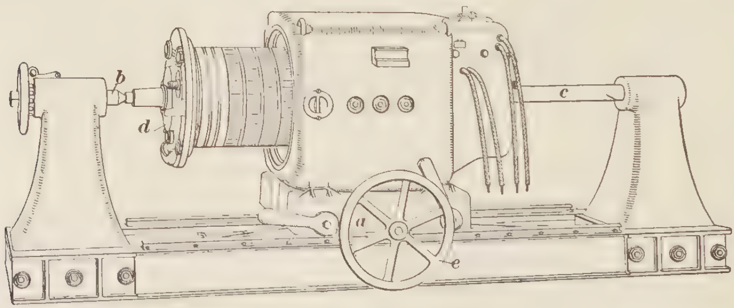


FIG. 13

ings and economizing space, because with these large motors it is difficult to find sufficient space for them between the wheel hubs. Openings *c*, *d* are provided on each side and on top of the motor in order to give access to the inside; under

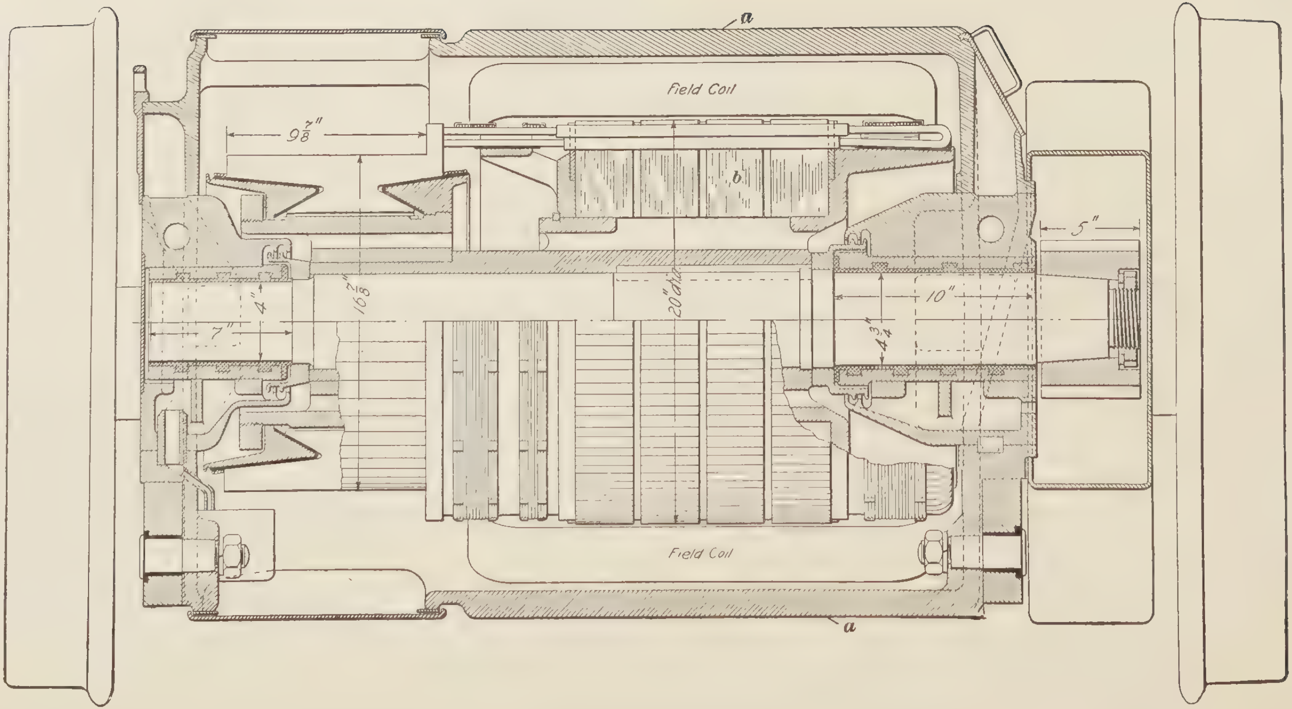
normal conditions, these openings are covered by plates bolted in place; one of the field coils is shown at *e*. With motors of the box-frame type, the armature is removed endwise by taking out either frame head and sliding the armature through the opening. Fig. 13 shows a stand by means of which armatures can be easily removed from this type of field. The motor is placed on a sliding carriage *a* and the armature held between centers *b*, *c*. After the frame head *d* has been loosened, the field can be moved to the right by turning wheel *e*, thus leaving the armature exposed.

WESTINGHOUSE NO. 86 MOTOR

29. Fig. 14 is a sectional view of a Westinghouse No. 86 motor, having an output of 200 horsepower based on the 1-hour rating, and intended for the same class of work as the G. E. 69. The arrangement of the inwardly projecting bearings is clearly shown—the bearing at the pinion end projecting under the armature head and that at the other end projecting under the commutator. The field is made in two parts and the four poles are arranged diagonally instead of vertically and horizontally, as in the large General Electric motors in which the box type of frame is used. In nearly all large motors, both armature and field coils are wound with copper strip or bar instead of wire.

WESTINGHOUSE NO. 56 MOTOR

30. The motor shown in Fig. 15 is typical of a number of Westinghouse motors that vary in size but have the same general construction. This motor, the No. 56, is designed for the heavier kinds of city and suburban traffic, and is capable of carrying continuously a current of 50 amperes at an average pressure of 300 volts. On the basis of a 1-hour rating, its capacity would be about 60 horsepower. In Fig. 15, *A*, *A'* are the top and lower halves of the field frame, which is made of mild cast steel; lid *C* may be thrown back to get at the commutator and brushes. The armature



a
Field Coil
$9\frac{7}{8}''$
b
$5''$
$16\frac{7}{8}''$
$20''$ dia
$4''$
$7''$
$10''$
$4\frac{3}{4}''$
Field Coil
a

Fig 14

leads are shown at a, a' and the field leads at f, f'; post g is used for making the connection to the ground. The lug l is for hanging the motor when a nose suspension is used. With a cradle suspension, the side bars pass through the rectangular openings r at each end of the motor. The wires

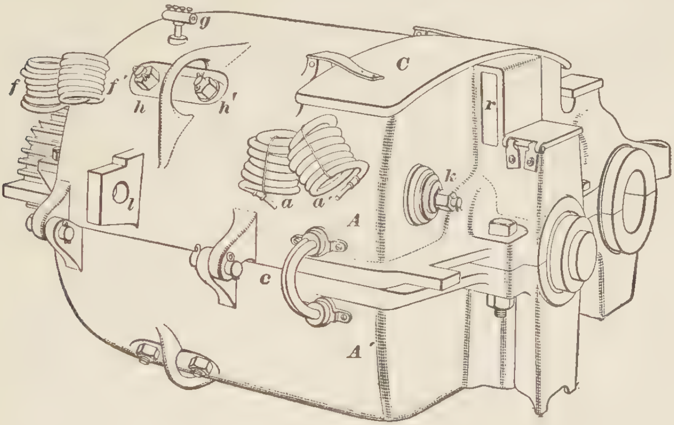


FIG. 15

shown at c connect the top and bottom field coils together. The pole pieces are laminated and held in position by the bolts h, h', and the armature bearings are so arranged that the armature may be either swung down with the lower half or retained in the upper half.

ALTERNATING-CURRENT MOTORS

31. Alternating-current motors for railway work have so far been used comparatively little. Both the Westinghouse and General Electric motors are of the series type and their construction and general appearance are on the whole very similar to ordinary direct-current motors; in fact, they will operate on either direct or alternating current. One of the chief points of difference is that the whole magnetic circuit of the alternating-current motor field must be laminated in order to prevent eddy-current loss due to the alternating magnetic flux. The field core is built up of iron

stampings and slipped inside of a housing, so that the outward appearance and general mechanical construction are practically the same as for direct-current motors. The motors also include some special features in design, introduced to prevent sparking at the brushes. In the General Electric so-called compensated motors, the field winding instead of being wound on definite projecting poles, is distributed in slots in a manner similar to the field winding of an induction motor. The compensating winding counteracts the effects of armature reaction and prevents sparking. In the Westinghouse motors, the field coils are wound on projecting pole pieces. In both types of motor, the construction of armature and commutator is practically the same as for direct-current motors.

It is much easier to build satisfactory alternating-current motors for low voltage than for high voltage, and as the alternating current is easily stepped down to any voltage desired, they are usually wound for 200 to 225 volts, instead of 500 volts. When it is desired to operate the motors on 500-volt direct current, as well as on alternating current, they are connected permanently in series, in pairs. The standard frequency is 25 cycles per second, since a low frequency is necessary for satisfactory operation of motors of this type.

MOTOR LUBRICATION

32. The question of proper lubrication for railway motors is an important one. Insufficient lubrication not only causes a waste of power but it may lead to much damage to the equipment by allowing the bearings to wear so as to let the armature down on to the pole pieces. In the older motors grease was used as a lubricant, but it is fast being superseded by oil. Grease does not feed down until the bearing becomes warm enough to melt it, whereas oil furnishes continuous lubrication. On many of the later motors, lubrication is effected by means of wool waste saturated with oil, as described in connection with the G. E. 70 motor, this method having proved very simple and efficient.

In order to allow oil lubrication on old motors provided with grease cups, a number of oil lubricators have been designed. In some cases, these have not proved satisfactory because the oil fed down while the cars were standing in the barn at night, thus causing much waste. Fig. 16 shows an oil lubricator, made by the Standard Automatic Lubricator Company, for attaching to motors built for grease lubrication. The cast-iron oil cup *a*, provided with a lid *b* normally held closed by a spring, is mounted on top of the grease cup; the cover on the old cup is removed and *a* is held in place by the projecting lug *c*; the lower part *d* projects into the grease cup, which is filled with loosely packed waste. The opening in *d* is closed by a ball valve *e* held against its seat by a spring *f*, the tension on which is adjusted by nut *g* so that no oil can pass out while the car is standing still. When the car is in motion, the vibration and knocks to which it is subjected unseat *e* so that oil can flow on to the waste. Thus, there is no waste of oil while the car is standing still, but the oil feeds as long as the car is in motion. For shafts less than $2\frac{3}{4}$ inches diameter, a feed of $\frac{1}{8}$ inch of oil in the cup should be sufficient for 100 miles of car travel; for larger shafting a feed of about $\frac{3}{16}$ inch should be allowed.

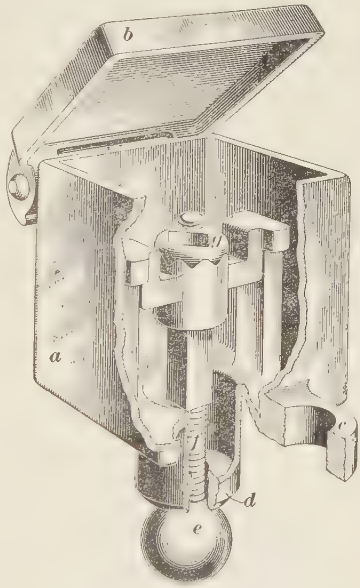
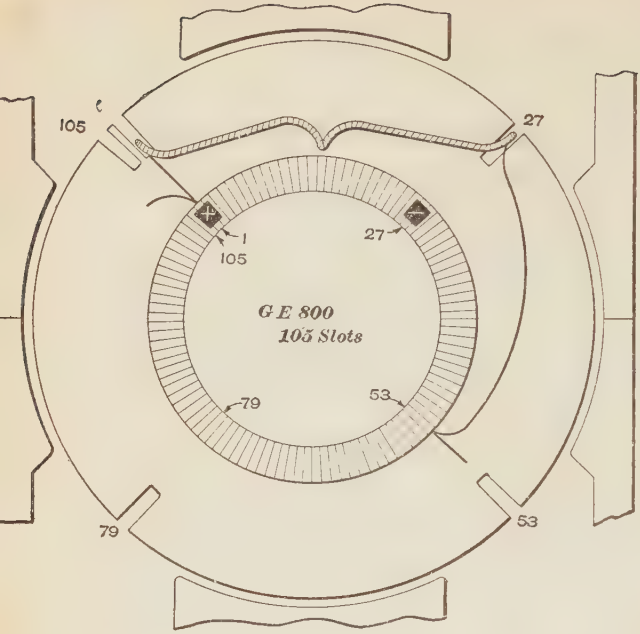


FIG. 16

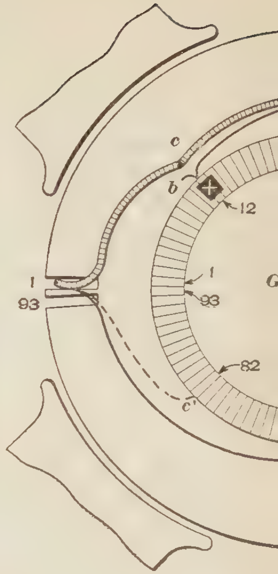
ARMATURE WINDINGS FOR RAILWAY MOTORS

33. The armatures of railway motors are nearly always of the four-pole drum type; on some of the older motors ring windings were used, but these are now obsolete. The coils are wound on forms, and after being covered with insulating tape are placed in the slots on the core. They are always arranged in two layers so as to cross each other at the ends without interfering, and are connected to the commutator to form a two-circuit or series winding. The total number of coils must fulfil the relation $C = \frac{p}{2} \times Y \pm 1$, where C is the number of coils, p the number of poles, and Y the pitch of the coil terminals on the commutator; thus, if one end of a coil connected to bar 1, and the other to bar 53, the pitch Y would be $53 - 1 = 52$. Since in nearly all railway motors $p = 4$, $\frac{p}{2} = 2$ and $\frac{p}{2} \times Y$ is an even number; hence, $\frac{p}{2} \times Y \pm 1$ is an odd number no matter what the value of Y may be.

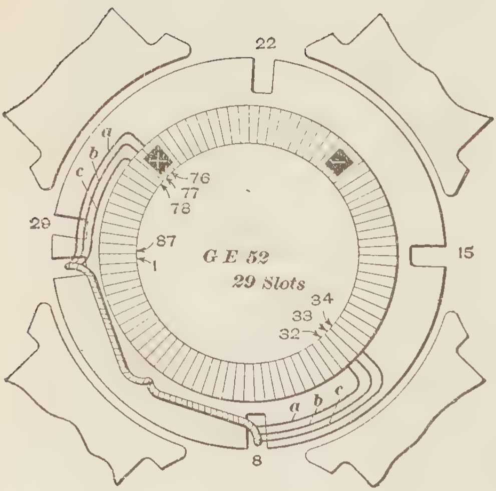
In many armatures, two or more coils are taped together to form a winding element and the number of coils may therefore be different from the number of slots. If there are 2 or 4 coils per slot, the total number of coils will be even no matter what the number of slots may be, and the winding will therefore not connect properly. For example, take the Westinghouse 12A armature, Fig. 18; there are 47 slots and each winding element consists of 2 coils taped together; hence, there are 94 coils. But 94 coils will not fulfil the relation $C = \frac{p}{2} \times Y \pm 1$, because the number of coils must be odd; hence, one coil is cut out by cutting off its terminals and taping the ends over. This leaves 93 coils to be connected and the dead, or "dummy," coil is left in the armature simply to maintain the mechanical balance. These so-called dummy coils are found in a number of armatures, but the later motors are generally designed so as to avoid them.



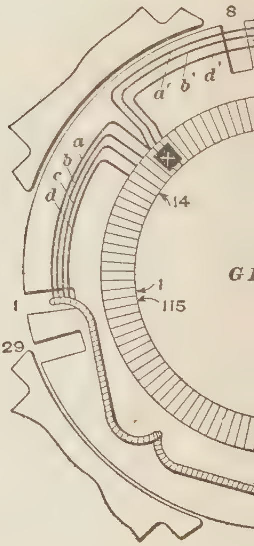
105
27
1
105
27
G E 800
105 Slots
79
53
79
53



c
b
12
1
93
1
93
82
c'

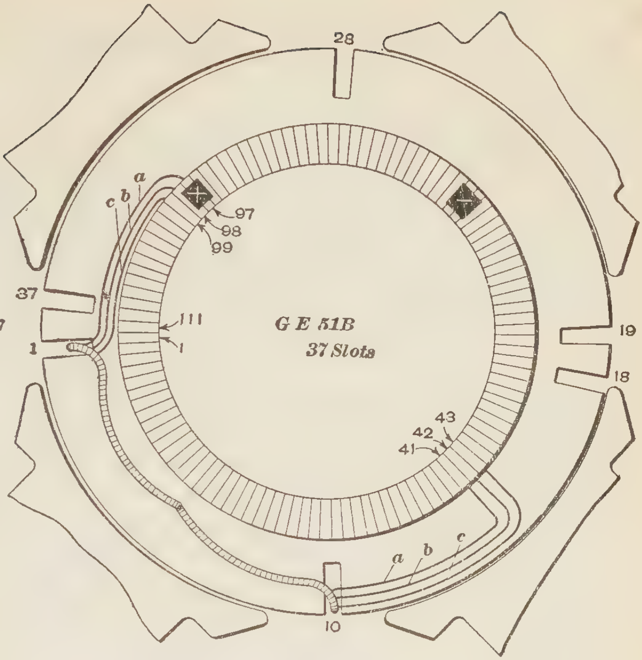


22
a
b
c
76
77
78
29
87
1
G E 52
29 Slots
15
34
33
32
a
b
c
8

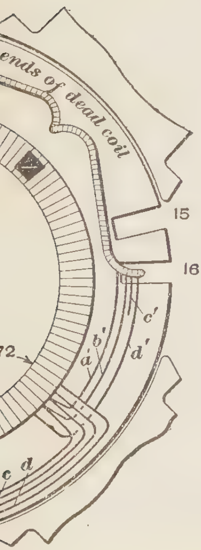


8
a'
b'
d'
a
b
c
d
14
1
115
1
29

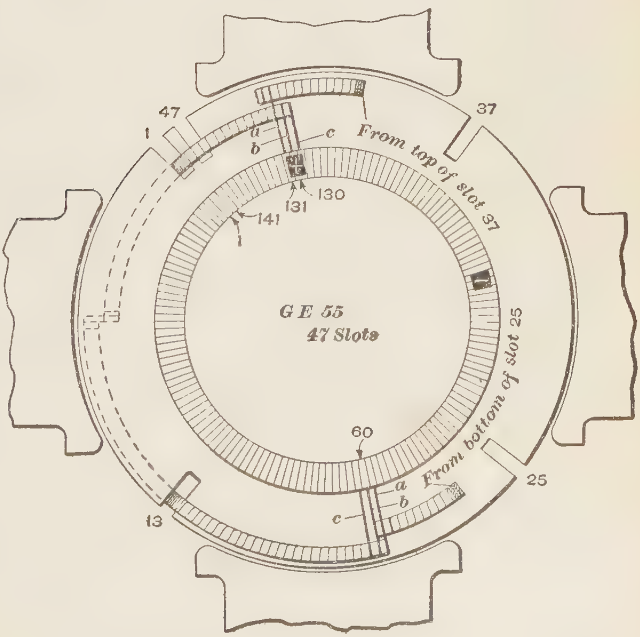
b'
47



G E 51B
37 Slots
28
37
1
19
18
10
a
b
c
97
98
99
111
1
43
42
41



ends of dead coil
15
16
c'
b'
d'
a'
c
d



G E 55
47 Slots
From top of slot 37
From bottom of slot 25
47
1
37
25
13
a
b
c
130
131
141
1
60

34. The series winding has many advantages for railway-motor work, not the least of which is that it requires only two brushes; if four brushes were used, as would be necessary with a parallel winding, the lower brushes would be very hard to get at. Another advantage is that uneven centering of the armature due to wear in the bearings or other causes does not produce an unbalanced electrical condition, as might be the case with a parallel-wound armature not provided with equalizing rings.

It is not possible to show here all the connections for standard railway-motor armatures. Figs. 17 and 18 show a number of the most common ones, and if these are thoroughly understood there will be no difficulty in following out the connections of other armatures. For convenience in indicating the connections, a slot on the core is taken and called *slot No. 1*, then the commutator bar directly in line with slot 1 is marked No. 1. Practice varies as to the methods of numbering and counting off the bars, but the three main things to be considered are: the throw of the coil leads, the number of bars between leads, and the spread of the coils on the core. The throw of the leads determines the location of the brushes with respect to the pole pieces. For example, in the G. E. 800 armature, Fig. 17, one coil lead is brought straight out to the commutator bar because the pole pieces are arranged vertically and horizontally and it is desired to have the brushes located on the diagonals as shown. In the Westinghouse No. 3, Fig. 18, both coil leads are given a throw so as to bring the brushes as shown, the pole pieces being located on the diagonal; for example, the lead coming from the bottom of slot 1 is connected to bar 84, found by counting off thirteen to the left from bar 1. In the G. E. 55, the two throws are unequal, thus bringing the brushes into a position at a slight angle from the vertical and horizontal.

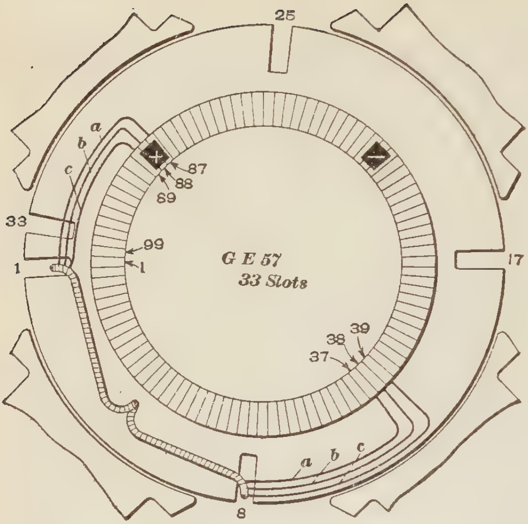
35. G. E. 800.—This armature, Fig. 17, has 105 slots and 105 coils. The coil pitch is 26 slots; i. e., the two sides of a coil drop into slots 1 and 27. The coil terminals have a

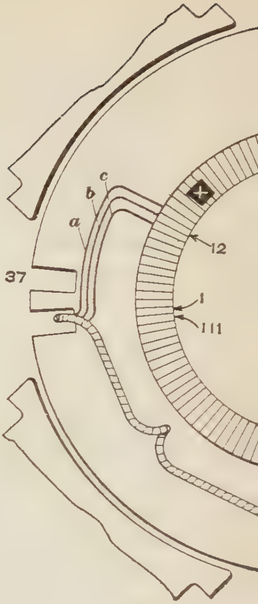
pitch of 52 bars on the commutator, or if one end connects to bar 1, the other connects to $1 + 52$ or bar 53. Thus, $Y = 52$, $105 = 2 \times 52 + 1$, and the requirements for a two-circuit winding are fulfilled. The second coil would be dropped into slots 2 and 28, and its terminals connected to bars 2 and 54. After the first coil has been placed in position and its leads connected the others follow in rotation, so that in nearly all the diagrams only one coil is shown.

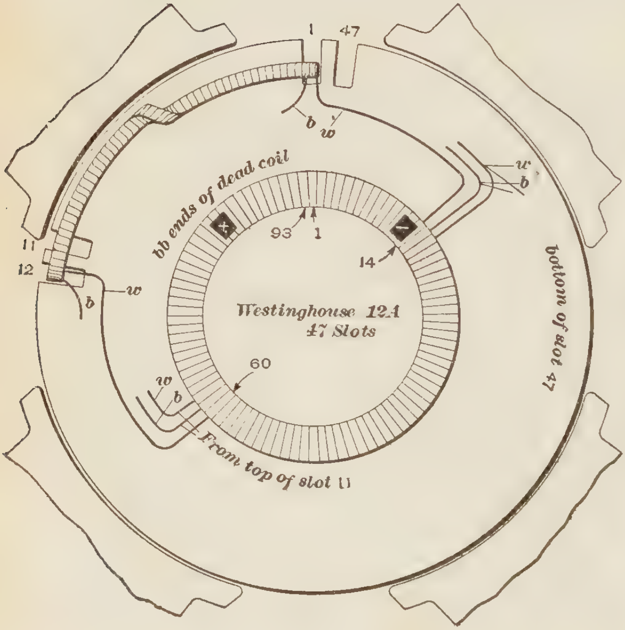
36. G. E. 1,000.—The G. E. 1,000 armature, Fig. 17, has 93 slots and 93 coils having a pitch of 23 slots on the core. The pitch of the coil terminals on the commutator is 46 bars. The coil lead *a b* is thrown back as shown, but in many cases it is taped in with the coil and appears as a lead coming out at the bend *c* of the coil and is therefore connected to the bar directly opposite the bend. This armature could also be connected as shown by the dotted lines, thus making the coil leads more symmetrical. With the same field connections, an armature connected as shown by the dotted lines would run in the opposite direction from one connected as shown by the full lines.

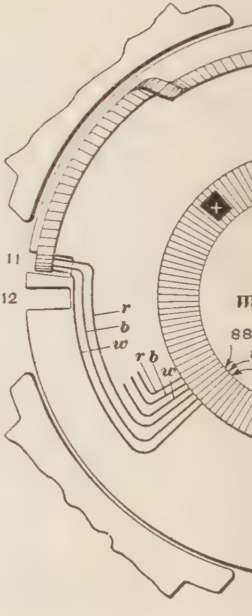
37. G. E. 51B.—The G. E. 51B armature, Fig. 17, has 37 slots, 3 coils per slot, or 111 coils. This is an example of an armature where each winding unit consists of 3 coils taped together. The pitch on the armature core is 9, the coils dropping into slots 1 and 10. The corresponding coil leads are marked *a*, *b*, *c*, and the throw is the same at each side of the coil, thus bringing the brushes opposite the center of the pole pieces. The pitch of the coil leads on the commutator is 55. The commutator pitch Y in any of the diagrams can be found as follows: Take, for example, the G. E. 51B, and call the bar to which the upper middle lead *b* is connected bar 1, instead of 98 as marked. Then count around under the coil until the bar to which lower lead *b* connects is reached. This will be bar 56, and the commutator pitch Y is therefore $56 - 1 = 55$.

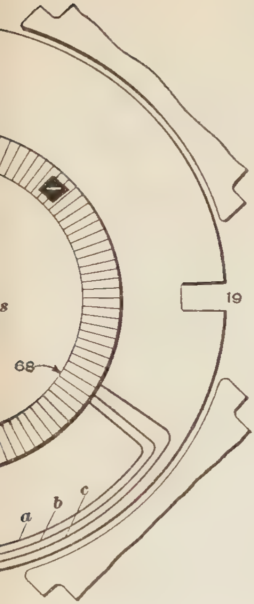
38. G. E. 52.—The G. E. 52 armature, Fig. 17, has 29 slots; 3 coils per slot, or 87 coils; the coils span 7 slots.

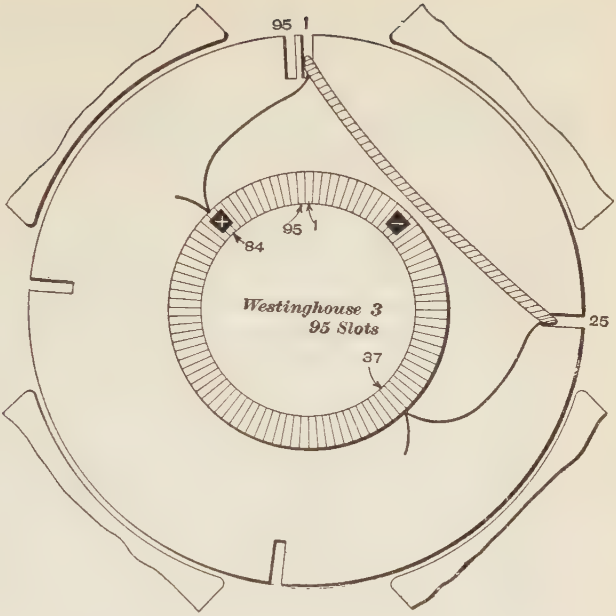

25
a
b
c
33
1
87
88
89
99
1
G E 57
33 Slots
17
39
38
37
a
b
c
8

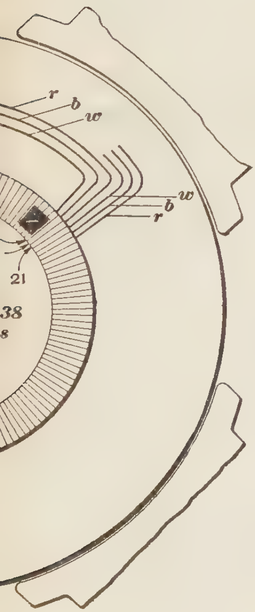

c
b
a
12
37
1
111

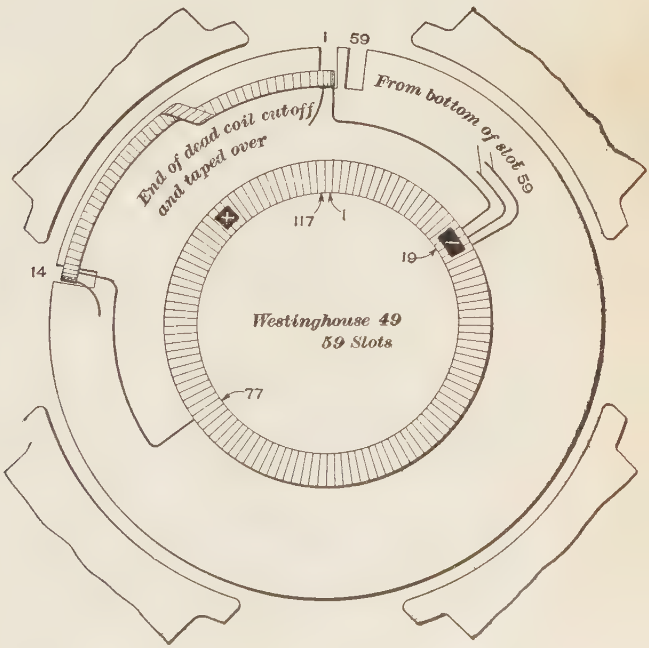

1
47
b
w
w
b
bb ends of dead coil
93
1
14
11
12
w
b
Westinghouse 12A
47 Slots
bottom of slot 47
60
w
b
From top of slot 11


11
12
r
b
w
r
b
w
88


19
68
a
b
c


95 1
95
1
84
Westinghouse 3
95 Slots
37
25


r
b
w
21
38


1
59
From bottom of slot 59
End of dead coil cutoff
and taped over
117
1
19
14
Westinghouse 49
59 Slots
77

Each winding unit consists of 3 coils taped together and corresponding terminals of the 3 coils are lettered a, b, c. The span, or pitch, on the commutator is 43, and $87 = 2 \times 43 + 1$.

39. G. E. 54.—The G. E. 54 armature, Fig. 17, has 29 slots; 4 coils per slot, or 115 coils. The coils have a pitch of 7 slots on the core. This is an example of a winding where one coil has to be left dead in order that the coils may connect up to form a two-circuit closed-coil winding. If all the coils were used, there would be $29 \times 4 = 116$, and this number would not fulfil the relation $C = \frac{p}{2} Y \pm 1$. If an attempt were made to use 116 coils, the winding would close on itself after progressing once around the commutator. By cutting out 1 coil and using a pitch of 57 on the commutator, we have $115 = 2 \times 57 + 1$ and the winding requirements are fulfilled. Fig. 17 shows one of the regular winding units in place and also the unit with 1 coil cut out. Usually in winding armatures where there is a dummy coil, the first coil put on contains the dummy, though it makes no difference which coil is selected.

40. G. E. 55.—This motor is of large size and has an armature wound with copper bar. The field frame is of the box type, and in order to bring the brushes opposite the opening in the frame the leads of the coil connections, Fig. 17, are different on the two ends. The armature has 47 slots with 3 coils per slot, each coil being a single loop of copper bar. The sides of a winding unit have a pitch of 12 slots on the armature core.

41. G. E. 57.—The G. E. 57 armature, Fig. 18, has 33 slots, 3 coils per slot, or 99 coils. The winding units have a pitch of 7 slots; i. e., the unit is placed in slots 1 and 8. The pitch on the commutator is 49, and $99 = 2 \times 49 + 1$.

42. G. E. 67.—The G. E. 67 armature, Fig. 18, has 37 slots, 3 coils per slot, or 111 coils. The coil pitch on the armature core is 9, and the pitch of the coil leads on the commutator is 55.

43. Westinghouse No. 3.—The Westinghouse No. 3 armature, Fig. 18, has 95 slots and 95 coils. The pitch of coils on armature core is 24. The pitch of coil leads on commutator is 48, and $95 = 2 \times 48 - 1$.

44. Westinghouse No. 12 or 12A.—The Westinghouse No. 12 or 12A armature, Fig. 18, has 47 slots, 2 coils per slot, or 93 coils. The pitch of the coils on the core is 11 slots. This armature has a dummy coil, so that the number of coils to be connected is one less than twice the number of slots. In order to distinguish the corresponding ends on each winding unit, they are marked white and black, as indicated by the letters *w* and *b*.

45. Westinghouse No. 38 or 38B.—The Westinghouse No. 38 or 38B armature, Fig. 18, has 45 slots, 3 coils per slot, or 135 coils. The coil pitch on the armature core is 10, the coils dropping into slots 1 and 11. The coil terminals are marked red, black, and white, as indicated by the letters *r*, *b*, and *w*.

46. Westinghouse No. 49.—The Westinghouse No. 49 armature, Fig. 18, has 59 slots, 2 coils per slot, or 117 coils. This armature has a dummy coil, otherwise the number of coils would be even and the armature would not connect up. The coil pitch on the armature core is 13.

FIELD COILS

47. One of the most common sources of trouble in connection with street-railway motors is wrongly placed or connected field coils. Few have any idea of the great amount of trouble a wrongly connected field coil may cause; its effect is felt long after the trouble has been found and removed. It not only injures itself, but it injures the other field coils and the armature. The armature probably heats to such an extent that the commutator connections become unsoldered and the fields gradually bake inside. The chances are that before the trouble is discovered and removed there may be grounded brush holders, armatures, or

fields, due to the current jumping across to the frame of the motor, because the weak fields in the first place cause poor commutation, and in the second place reduce the counter E. M. F. and allow more current to flow than the brushes can stand. It is safe to say that one-half of the trouble on cars turned in for blowing fuses can be traced directly or indirectly to defects in the field coils.

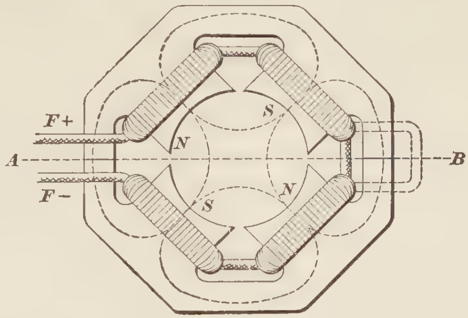


FIG. 19

Fig. 19 shows a section through a four-pole motor with a coil on each pole; the coils are so connected that the pole pieces alternate in polarity. In Fig. 20, the coils are not shown but the top left-hand coil is supposed to be connected incorrectly, with the result that the lines of force are very much twisted out of their path. However, it will be noticed that two sides of the four-sided figure made by the path of the lines of force can still be seen. Part of the armature is therefore effective, and the car will run on the faulty motor, but the brushes will spark badly, and there will be great consumption of current. The large current soon roasts the insulation on the coils, thus short-circuiting the turns and making matters still worse.

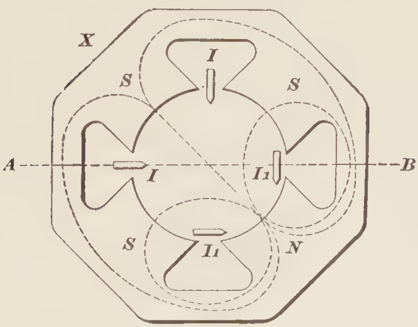


FIG. 20

Even if field coils are not incorrectly connected, they will in time become roasted, especially if the motors are worked hard. The insulation may become so charred as to allow

current to pass from turn to turn without encircling the pole piece, thus decreasing the magnetizing power of the coil. The field coils should therefore be tested from time to time to make sure that there is no short-circuiting due to roasting or other causes. In order to permit such tests to be carried out quickly, a number of special testing instruments have been devised. If a coil becomes short-circuited, its resistance measured between terminals will be lower than normal. Some of the field-coil testing instruments are a modified form of Wheatstone bridge, by which the resistance of a coil can be rapidly measured and compared with that of a coil known to be all right.

48. Conant Field-Coil Tester.—Railway-motor field coils are wound with a few turns of heavy wire; hence, their resistance is very low and it is difficult to make accurate resistance measurements with any form of bridge that can be handled quickly in a motor repair shop. The inductance of a field coil, as compared with a good coil, is more easily determined, and any change in the effective number of turns has a marked effect on the inductance, because, other things being equal, the inductance varies as the square of the number of turns. In the field-coil tester of Mr. R. W. Conant, the inductances of two field coils are balanced against two adjustable inductances in about the same manner as resistances are balanced in a Wheatstone bridge. The principle of the instrument will be understood from Fig. 21. A and B are two coils, one of which A is known to be all right, while B is to be tested. Connection is made to the cable leads by means of points f, f that are worked through the rubber insulation until they make contact with the strands of wire; in this way temporary connections are quickly made. Two coils a, b with iron cores that can be moved into or out of them are connected in series, as shown. The coils a, A, b, B correspond to the four arms of a Wheatstone bridge, but instead of balancing the resistances of a and b against those of A and B their inductances are balanced by varying the inductances of a and b. If, for example, the iron core a_1 is

moved into a, the effect is to increase the inductance of a, and vice versa. A few cells c send a current through the coils, and in order that induced E. M. F.'s may be set up, the current is interrupted by a clockwork mechanism d that drives a toothed contact wheel. A telephone is connected at e in order to indicate when the instrument is balanced. Suppose, for the present, that A and B are perfect coils and

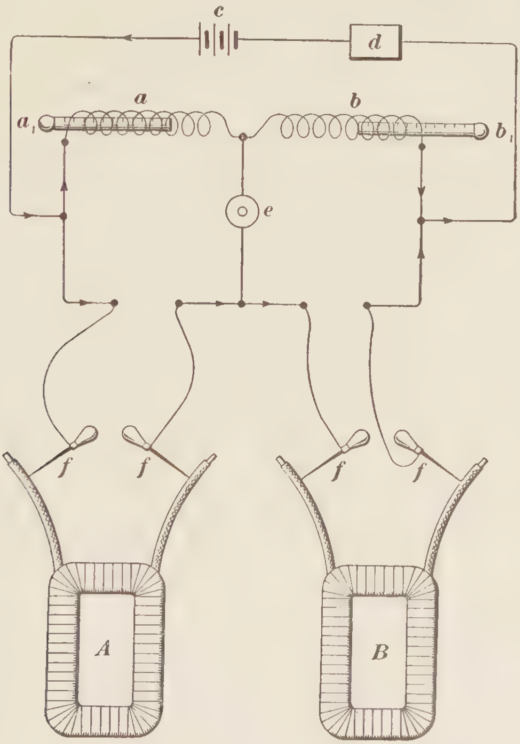


FIG. 21

alike in every particular. The minimum sound will then be obtained when cores a_1 and b_1 are adjusted so that the induced E. M. F.'s in a, b, A, B are equal, and the position of the cores can be noted by the graduations marked on them. If, however, coil B is defective because of a number of short-circuited turns, its inductance will be less than that

of A, and core b_1 must be drawn out farther than a_1 in order to obtain a balance; i. e., the inductance of b must be made less than that of a. In this manner the condition of a coil, as compared with a good coil, can be quickly determined, and from a knowledge of the readings obtained with good and bad coils it can be easily determined whether a given coil should be left in service or taken out and repaired. In another form of tester working on much the same principle, the operating current is obtained by connecting the instrument to a 500-volt lamp circuit of five lamps in series, the instrument taking the place of one of the lamps. This supplies about $\frac{1}{2}$ ampere; a magnetic vibrator is used to interrupt the current.

SPEED CONTROL

RHEOSTATIC CONTROL

49. Since the speed of a series motor can be varied by inserting an adjustable resistance in series, the first method of controlling the speed of street cars was by means of a resistance used in connection with a **controller**, or pair of controllers, by means of which the amount of resistance could be varied. This is known as the *rheostatic method of control*. It can be used with one or more motors, but it is now seldom employed for regular street-railway work, because it is wasteful of power, especially at the lower speeds. It is, however, used in those cases where only one motor is to be controlled and where gradual variations in speed are desired. It is employed to some extent in connection with mine-haulage plants and hoisting apparatus; also for cars operated by a single motor.

On account of the somewhat extended use of rheostatic control in connection with haulage and hoisting apparatus, some of its more important features will be considered briefly. This will also serve as a good introduction to the widely used series-parallel method described later.

R11 CONTROLLER

50. General Construction.—Fig. 22 shows a rheostatic controller designed by the General Electric Company for the control of cars, haulage locomotives, or hoisting motors; it is known as the **R11 controller** and was formerly called the KR. All General Electric type R controllers are

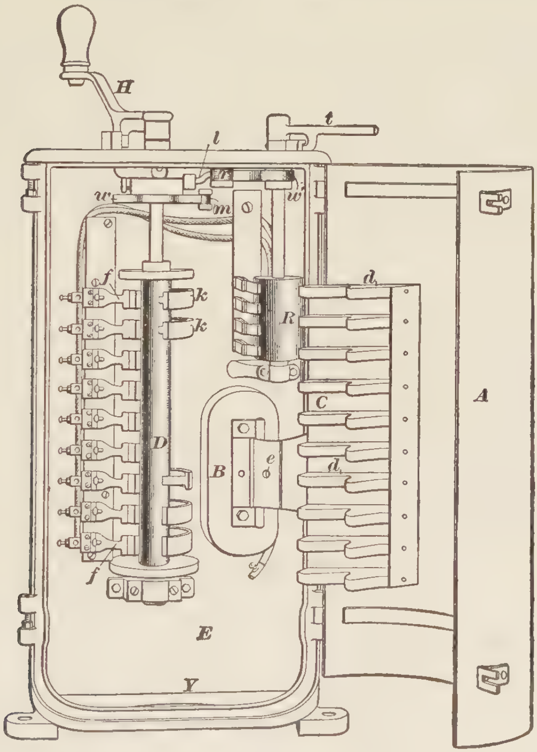


FIG. 22

intended for rheostatic control. This controller will be considered in detail because it contains many of the features found on controllers used on street cars and will serve as a good introduction to the study of them. It is designed to handle one 50-horsepower 500-volt motor or one 25-horsepower 220-volt motor; i. e., its contacts are large enough to

carry about 75 amperes. The figure shows the cover *A* thrown back so as to expose the working parts. The changes in the connections are effected by a *cylinder*, or *drum*, *D*, provided with contact segments that make connection with fingers *f*, *f* when the cylinder is rotated by means of the operating handle *H*. This controller is of the magnetic blow-out type, because a magnetic field is used to extinguish the arc that would otherwise form at the contact tips and cause blistering and burning. This method of preventing arcing has proved very effective. *B* is the coil that sets up the magnetic field necessary to blow out the arc, and is therefore called the *blow-out coil*. The iron back of the controller forms one pole piece and the hinged polar extension *C* the other; pole piece *C* is shown swung back so as to give access to the power

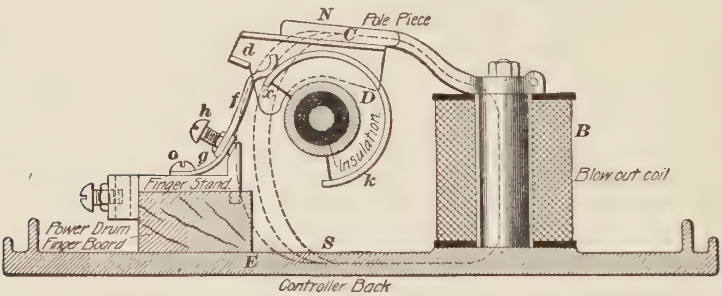


Fig. 23

cylinder *D*, but when the controller is in use, *C* is swung over and held in position by a bolt passing through hole *e*. Fig. 23 shows the relation of the pole piece *C*, cylinder *D*, and the controller back *E* when the pole piece is swung into position. The pieces *d* are *arc guards*, made of vulcabeston (vulcanized asbestos); they pass between the contact segments and prevent arcing across from segment to segment. All the current supplied to the car passes through blow-out coil *B* and sets up a magnetic field between *N* and *S*, as indicated by the curved dotted lines. When the cylinder is revolved far enough, tip *x* of segment *k* leaves finger *f* and an arc tends to form. This arc acts in the same way as a flexible wire carrying current, and is therefore forced across

the field and stretched out until it is broken. The action is practically instantaneous, so that there is little or no burning of the fingers and segments. Fingers *f* are stamped out of thick copper and are attached to a flat phosphor-bronze spring *g*, which is in turn fastened to the cast-brass finger stand by means of screws *o*, so that fingers can be replaced at any time. Screw *h* is for adjusting the amount that the finger drops when the segment passes from under it. This affects the pressure with which the fingers press on the segments, and they should be adjusted so as to drop about $\frac{1}{32}$ to $\frac{1}{16}$ inch. The cylinder segments should be rubbed frequently with a little vaseline so as to prevent wear and cutting.

51. Star Wheel, or Index Wheel.—The power cylinder is operated by means of handle *H*, Fig. 22, which fits on the top of the shaft. In order to compel the cylinder to take up a definite position corresponding to the various steps, it has a **star wheel**, or **index wheel**, *w* attached to the shaft. This engages with a spring-actuated roller *m*, which is pulled into the various notches on the star wheel and forces the cylinder into its proper position. It is this star wheel and roller that gives the movement of a controller handle its springy feeling.

52. Reverse Cylinder.—The reversing switch, or reverse cylinder, as it is called, is shown at *R*. This is much smaller and simpler than the power cylinder and is mounted in the upper right-hand corner of the controller. Its sole function is to reverse the armature connections in case it is desired to run the car in the opposite direction. It is not intended to turn the current on or off or effect any changes in the resistance. For this reason, the reverse cylinder is not provided with any device for suppressing arcing, and its contact fingers are somewhat lighter than those on the main cylinder.

53. Interlocking Device.—In order to make sure that the reverse cylinder shall not be moved while the current is on, the controller is provided with an interlocking device that makes it impossible to move the reverse cylinder unless

the power cylinder is at the off-position. The reverse cylinder shaft is provided with a star wheel w' having three notches, corresponding to the off-, ahead-, and back-positions. The lever carrying the roller r that engages this star wheel has a link l attached to it, which runs across to the hub of the star wheel w. The hub of w has a notch in it that comes opposite the end of l when the power cylinder D is at the off-position, and when the reverse handle t is moved, the end of link l is forced into the notch until the roller r passes over the projection on the star wheel w', when l falls back far enough to allow D to be turned. At any position of D other than the off-position, there is no notch opposite the end of l; hence, when an attempt is made to move t, link l butts against the hub and the reverse cylinder is locked.

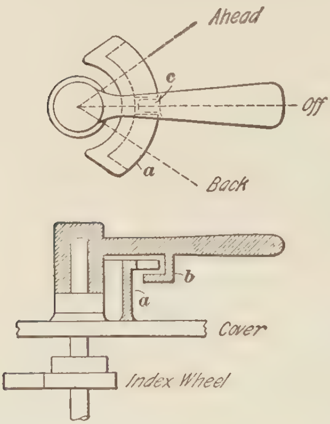


Fig. 24

When the reverse lever points ahead, the car runs forwards, and when it points back, the car runs backwards.

The reverse handle is also arranged so that it cannot be removed unless the power drum is at the off-position. An L guard a, Fig. 24, is cast on the controller cap and overhangs a hook b cast on the handle. A notch c is cut in the guard, so that the handle can be lifted off at the off-position and no other.

54. Operation.—This controller has six points, and a development of the cylinder with the various connections is shown in Fig. 25. This diagram shows a single motor, of which A' and F' are the armature and field, respectively, operated by a single controller. In this diagram and in those to follow, the cylinder segments are indicated by black bands, which represent the segments straightened or developed out flat. The finger stands on the power

cylinder and on the reverse cylinder connection boards are represented by vertical rows of black spots. The vertical dotted lines represent the various positions of the cylinder, and in studying the connections resulting from a movement of the operating handle to a given position, the developed cylinder can be considered as sliding under the contact fingers until it occupies a position indicated by the vertical

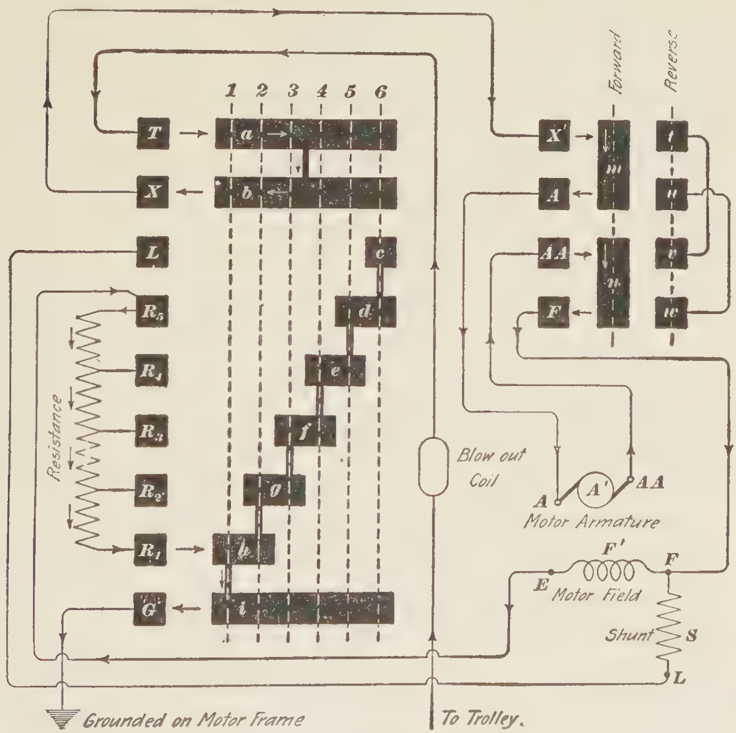


FIG. 25

dotted line that corresponds to the notch, or position, on which the handle is placed. In this case the power cylinder is in two parts. Contact segments a and b are connected together, but are insulated from c, d, e, f, g, h, and i, which are all connected together because they constitute a single casting. On the first notch, fingers T, X, R_1, and G make

contact with their respective cylinder segments; all the others hang over and touch nothing.

The path of the current on the first notch, indicated by the arrows, is: Trolley–blow-out coil–T–a–b–X–X'–m–A–A–armature A'–A A–A A–n–F–F–field F'–E–R_5 through the whole of the resistance–R_1–h–i–G–ground, thus completing the circuit from the trolley to the rail.

On the second notch, finger R_2 touches segment g, and when the current reaches R_5 it flows through three sections only of the resistance, because when it reaches R_2 it takes the path R_2–g–h–i–G. On the third notch, the section of resistance between R_2 and R_3 is cut out. On the fourth notch, that between R_3 and R_4, and on the fifth notch all the resistance is cut out, the path of the current there being: trolley–blow-out coil–T–a–b–X–X'–m–A–A–A'–A A–A A–n–F–F–$F'E$–R_5–d–e–f–g–h–i–G. The fifth notch, then, gives the highest speed that can be attained by simply cutting out resistance.

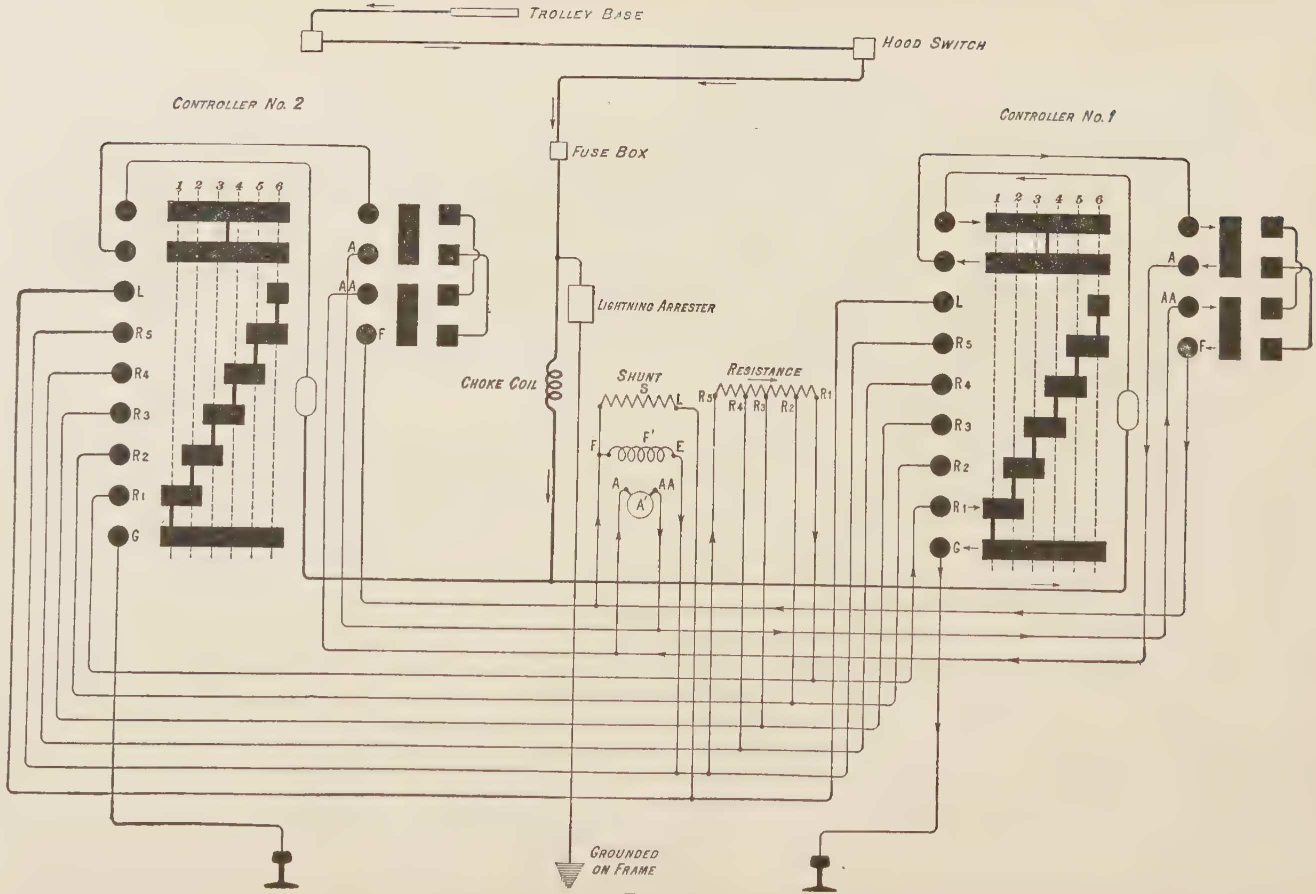
On this controller, a shunt S may be used and a sixth notch is provided, so that on it the shunt will be connected across the motor field coil, thereby weakening the field and increasing the speed. One end of the shunt is attached to F and the other to finger L. On the sixth notch, the path of the current is the same as on the fifth up to the point F; here the current divides, part of it taking the path F–F'–E–R_5–d–e–f–g–h–i–G, and the other part the path F–S–L–L–c–d–e–f–g–h–i–G, thus reducing the current in the field coil. Instead of weakening the field by means of a shunt, the same effect can be obtained by bringing out a tap from the field coil and connecting it to the wire L L. When the controller is placed on the last position, part of the field turns are cut out, thereby weakening the field and increasing the speed. These so-called *shunt* or *loop methods* of control are now little used for street-railway work; they introduce undesirable complications and it has been found that a sufficient range of speed can be secured without them. Most recent types of controllers are therefore designed for use without loops or shunts. It is easily seen that the

controller, Fig. 25, could be used without a shunt S by simply omitting the connection $L L$, in which case the speed on the sixth notch would be the same as on the fifth.

55. Operation of Reverse Switch.—If the motor is to be reversed, the reverse cylinder is thrown over, bringing contacts t, u, v, w under fingers X', A, $A A$, and F, respectively. When the current reaches X', it takes the path X'–t–v–$A A$–$A A$–A'–A–A–u–w–F. In other words, it flows in at the $A A$ end of the armature instead of at the A end as before, but it still flows in at the F end of the field, thus reversing the current through the armature, but not through the field. The lettering of the various connecting posts is that used by the General Electric Company.

56. Car With Two Rheostatic Controllers.—In Fig. 25, only one controller is shown, but on a car or mining locomotive two controllers, one on each end, are usually necessary. Fig. 26 shows two controllers connected together for the operation of a single motor. The corresponding connecting posts of the two controllers are connected together by the wires that run the length of the car. Of course, when one controller is in use, the other is at the off-position, because the handle of the reverse cylinder cannot be removed until the power is thrown off. The arrowheads show the path of the current when controller No. *1* is on the first notch. This is practically the same as that shown in Fig. 25, except that the parts are in a little different location. The wires in this and in the following diagrams are not supposed to touch each other where they cross unless there is a round dot placed at their point of intersection. The various combinations may be represented diagrammatically, as shown in Fig. 27. The first five steps differ from each other in the amount of resistance included, and the last step is the same as the fifth, with the exception that the field F is shunted.

When a rheostat is used continuously to control the speed, it must be proportioned so as to avoid overheating, and all the resistance notches may be used as running notches. With ordinary street cars, however, the resistance is not



TROLLEY BASE
HOOD SWITCH
CONTROLLER No. 2
CONTROLLER No. 1
FUSE BOX
LIGHTNING ARRESTER
CHOKE COIL
SHUNT
S
RESISTANCE
F'
A'
GROUNDED ON FRAME

FIG. 26

supposed to be used for speed-controlling purposes. It is only intended to give the car a smooth start and should not be used to run on. Before leaving the study of this controller, it may be well to notice that the resistance coils are here placed next to the ground, so that the current first enters the motor. In most controllers, the resistance is placed ahead of the motors; but on the whole, it makes no difference so far as the effect of the resistance itself goes; it sometimes does, however, make a difference in regard to

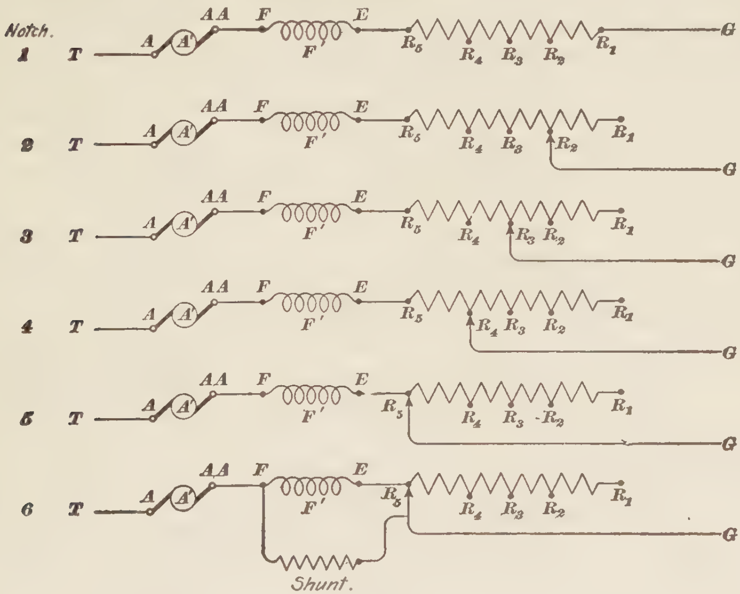


FIG. 27

the amount of trouble that arises on account of grounds occurring on the resistance. Also notice, in Fig. 26, that the post marked *A A* on controller No. *1* is connected to post *A* on controller No. *2*, and post *A A* on controller No. *2* is connected to post *A* on controller No. *1*. It is necessary to interchange the armature wires in this way so that the car will move forwards when the reverse handle on the end from which it is run points ahead.

SERIES-PARALLEL CONTROL

57. General Description.—The method of speed control now almost universally used for street-railway work is known as the **series-parallel** method. It enables the voltage applied to the motors to be cut down for slow-speed running without the use of resistance, and hence is more economical on low speeds than the rheostatic method. At least two motors per car are required; hence, this method is not applicable to single-motor equipments. For slow speed, the motors are connected in series, and for high speed, they are connected in parallel; hence the name series-parallel.

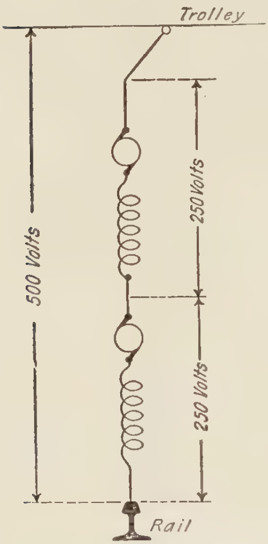


Fig. 28

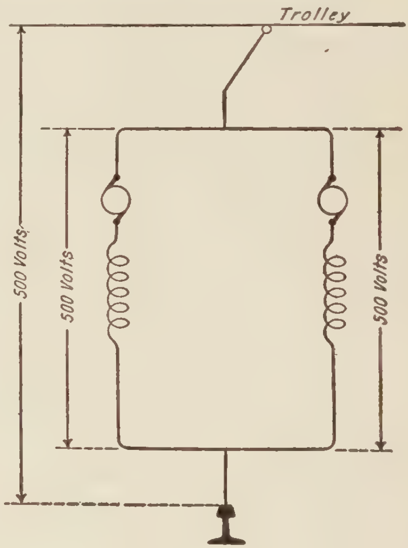


Fig. 29

Let us assume that the pressure is 500 volts; then, if the two motors on a car are connected in series, as shown in Fig. 28, the pressure across each motor will be only 250 volts. Each motor will then have to run at only about half its normal speed to generate the required counter E. M. F., and the result is that a slow speed is obtained without the use of any resistance.

When the higher speed is desired, the controller is thrown around to the "multiple notches" and effects the combinations necessary to change the motors from series to parallel. When they are in parallel, as shown in Fig. 29, a pressure of 500 volts is applied to each motor and the car runs at full speed. Of course, at starting it is necessary to include some resistance, and when changing from series to parallel, resistance is also cut in to prevent an excessive rush of current and to give a smooth acceleration to the car; but the resistance is cut out as soon as the car gets under headway and is not used on the running notches.

A great many types of series-parallel controller have been brought out, and it would be an endless task to describe all of them; the diagrams here given will, therefore, relate only to a few of the most commonly used types.

58. Types of Series-Parallel Controller.—The General Electric Company's series-parallel controllers are divided in two general types: type K and type L. Those designated by the letter K are intended for two or more series motors and include the feature of shunting, or short-circuiting, one of the motors when changing from series to parallel. For ordinary street cars, the K type is almost universally used, the most common controllers being the K2, K6, K10, K11, K12, and K14. Type L controllers are also intended for two or more series motors, but in changing from series to parallel, the power circuit is completely opened for an instant and then closed after the change from series to parallel has been made. Type L controllers are used mostly for large interurban cars equipped with heavy motors.

Another class of controller, known as type B, may be either rheostatic or series-parallel, but they are always provided with the necessary contacts and connections for the operation of electric brakes. Westinghouse controllers are designated in the same way as those of General Electric make and their construction is also the same.

K2 CONTROLLER

59. General Description.—Type K controllers embody many of the features described in connection with the type R controller. The magnetic blow-out is arranged in the same way, and the general mechanical construction is the same, though, of course, the type K is more complicated, because it must handle all the connections for two or more motors and effect the changes necessary to throw the motors from series to parallel. It is also provided with switches, by means of which either motor may be cut out, in case it becomes disabled, allowing the car to be operated on the other motor. The K2 controller is designed for use with shunts; i. e., on the last series notch the fields of both motors are shunted and the same is also the case on the last multiple notch. The controllers may, however, be used without shunts and they are frequently run in this way.

The K2 controller is used with two motors of 40 horsepower or under and has 9 notches. There are more positions than this, but only 9 of them are marked on the controller top, and the mechanism of the controller is so fixed that the handle cannot be easily made to rest anywhere except on a marked notch. This is done so that the cylinder will not hang between notches and cause burning inside the controller. Fig. 30 shows the controller with the door opened so that the inside parts can be seen.

In Fig. 30, *1* is the operating handle that turns the controller or power cylinder *2*; *3* is the reverse handle that turns the reverse cylinder *4*; *9, 9* are the fingers that make contact with the power cylinder and *6* is the blow-out magnet. The reverse cylinder has no blow-out coil, because it cannot be moved while the current is on. The *cut-out switches*, by means of which a disabled motor can be cut out, are shown at *7, 7*; *8* (in the lower right-hand corner) is the *connection board*, into which run all wires from the motors and other devices, as well as the ground and trolley wires. The terminals on the connecting board also connect to the various parts of the controller, as will be shown in another diagram. The door,

or cover *12*, swings back as shown, and the bolt and wrench *10* is used for holding the pole piece in place when it is swung over; *5, 5* are the arc guards. Both the power cylinder

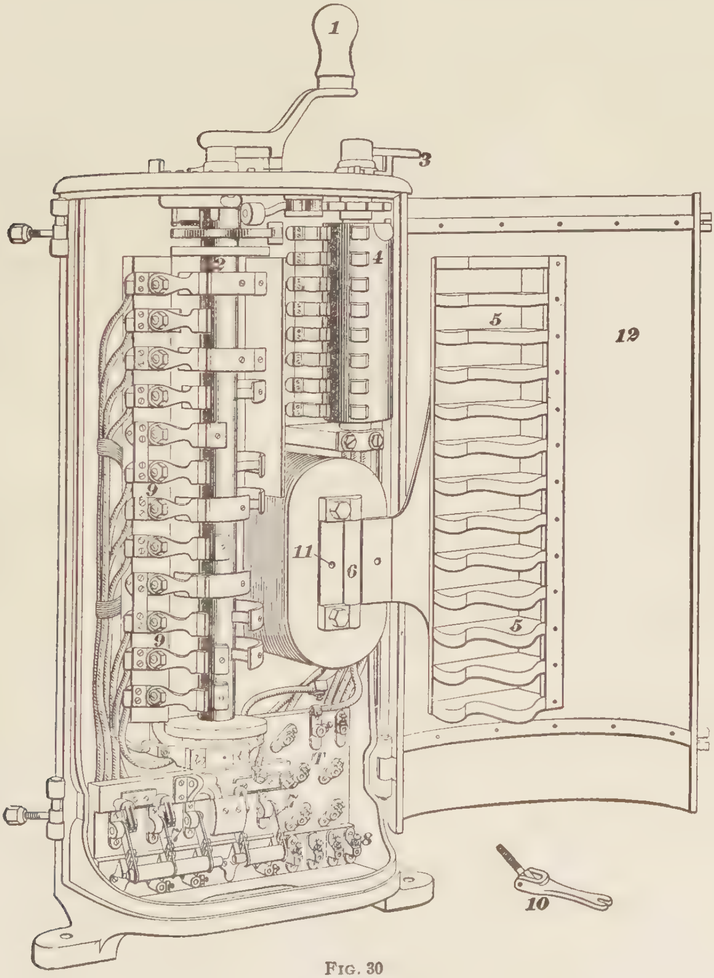


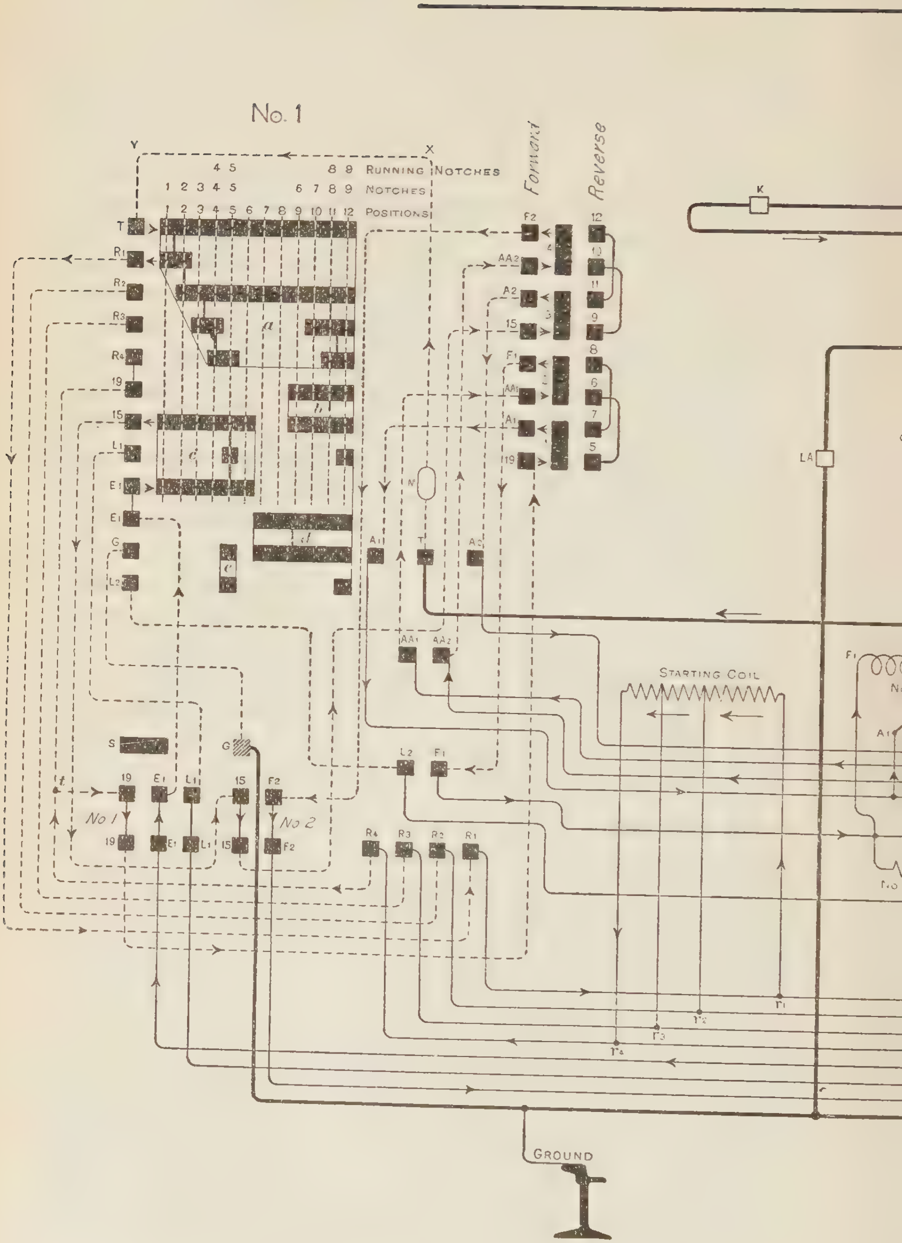
FIG. 30

and the reverse cylinder of this controller are longer than those of the rheostatic controller. The interlocking device between the two cylinders is practically the same on both, but

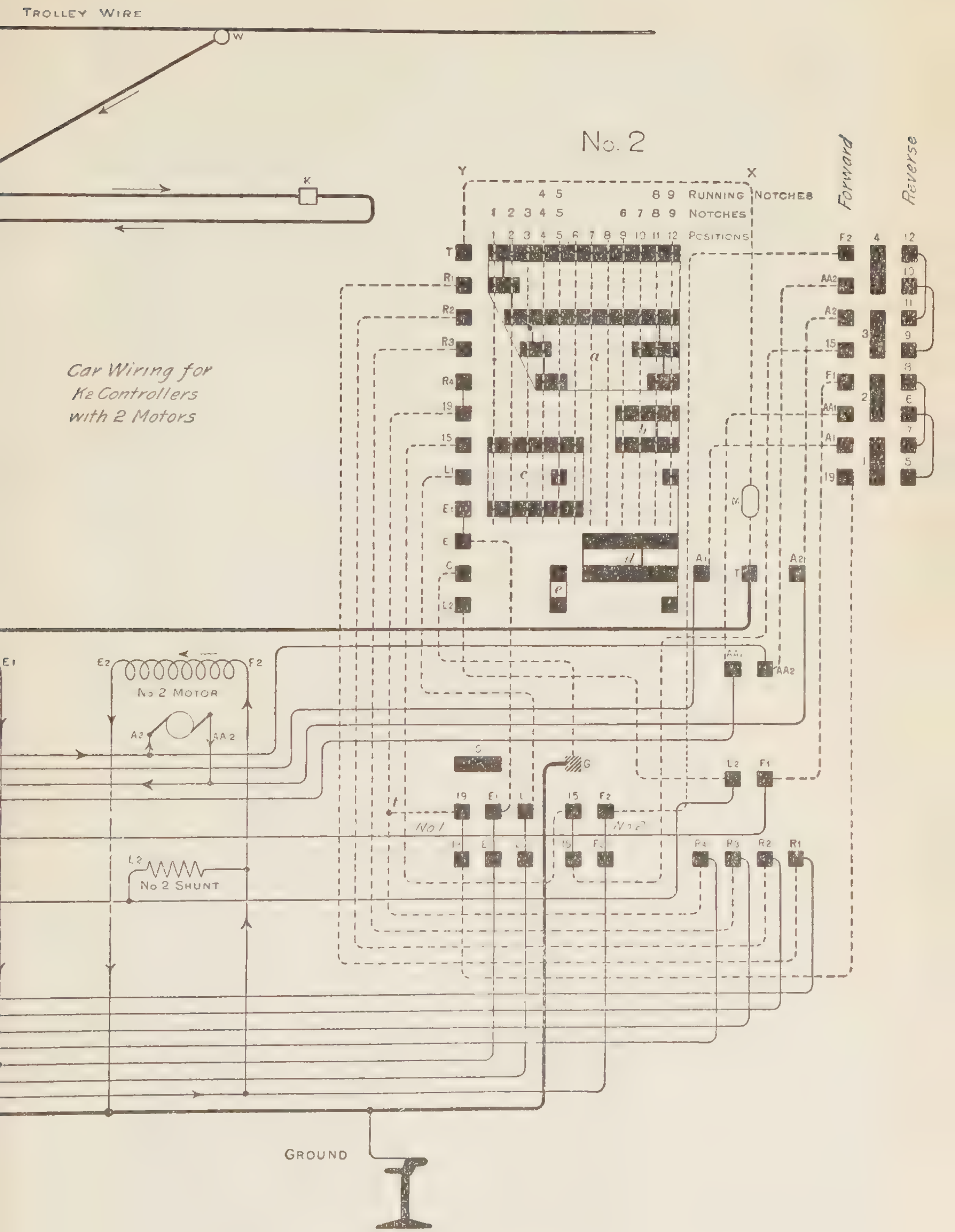
the connection board *8* is made necessary on account of the numerous connections and the addition of two cut-out switches *7, 7*.

60. Wiring Diagram.—Fig. 31 shows a diagram of wiring for two K2 controllers, the lettering of the various parts corresponding to that used by the General Electric Company. The operating cylinder is made of five castings a, b, c, d, e insulated from each other and from the shaft. There are in all twelve positions of the cylinder, as indicated by the vertical dotted lines, but only nine of these correspond to notches in the index wheel, Nos. *6*, *7*, and *8* being transition positions that are passed over quickly while the connections are being changed from series to parallel. Of the 9 notches, only 4 are running notches, these being *4* and *5*, *8* and *9*, as indicated by the numbers above the development of the power cylinder. On each of these 4 notches, the starting resistance is not in circuit; on notch *4*, the two motors are in series with all the resistance cut out, and on *5* the connections are the same as on *4* except that the fields are shunted by shunts L_1 and L_2. If shunts were not used, the speed on notch *5* would be the same as on *4*. On notches *8* and *9*, the motors are in parallel, the fields being shunted on notch *9*, thus giving the highest possible speed.

61. The path of the current on the first notch is, assuming No. *1* controller to be used with the reverse switch at the forward position, as follows, beginning at the trolley post T on the connection board of No. *1* controller: T–X–Y–T finger–casting a–finger R_1–post R_1–r_1–whole of starting coil to r_4–post R_4–t–*19* on cut-out switch–*19*–*19* finger on reverse switch–segment *1*–finger A_1–post A_1–A_1 brush on motor No. *1*–No. *1* armature–brush AA_1–post AA_1–AA_1 finger on reverse switch–segment *2*–finger F_1–post F_1–field terminal F_1–field to E_1–post E_1 on No. *1* cut-out switch–E_1–fingers $E_1 E_1$ on controller–casting c–finger *15*–post *15* on No. *2* cut-out switch–*15*–finger *15* on reverse switch–segment *3*–finger A_2–post A_2–brush A_2–No. *2* armature–brush AA_2–post AA_2–finger AA_2 on reverse switch–segment *4*–



No. 1
Running Notches
Notches
Positions
Forward
Reverse
Starting Coil
Ground
No 1
No 2



Trolley Wire
No. 2
Running Notches
Notches
Positions
Forward
Reverse
Car Wiring for K2 Controllers with 2 Motors
No 2 Motor
No 2 Shunt
Ground

finger F_2–post F_2–field terminal F_2–E_2–ground wire. This path is indicated by the arrowheads in Fig. 31, and it is seen that both motors are in series with all the starting resistance. As notches *2* and *3* are passed, the resistance sections are short-circuited by fingers R_2 and R_3 making contact with a and on the fourth notch the series running notch is used when low speed is desired. On the fifth notch, finger L_1 makes contact with c and L_2 and G with e, thus placing the shunts L_1 and L_2 in parallel with the fields. The sixth position is one of transition and gives the same combination as the second, part of the resistance being cut back into the circuit. On positions *7* and *8*, No. *2* motor is dropped out of circuit temporarily by fingers E_1 and *15* leaving casting c; at the same instant that a connection is made between E_1 and G (ground) by fingers E_1 and G making contact with segments d, thus maintaining the circuit through the No. *1* motor.

62. On position *9* (notch *6*), No. *2* motor is picked up in parallel with No. *1* and the last two sections of the resistance are in series as on positions *6*, *7*, and *8*. The path of the current on notch *6* is, therefore, starting from post R_4:

$$R_4\text{–}t\text{–}\begin{cases}19\text{–}19\text{–}19\text{–}1\text{–}A_1\text{–}A_1\text{–}A_1\text{–}A\,A_1\text{–}A\,A_1\text{–}\\ 19\text{–}b\text{–}15\text{–}15\text{–}15\text{–}15\text{–}3\text{–}A_2\text{–}A_2\text{–}A_2\text{–}\end{cases}$$
$$\left.\begin{array}{l}A\,A_1\text{–}2\text{–}F_1\text{–}F_1\text{–}F_1\text{–}E_1\text{–}E_1\text{–}E_1\text{–}E_1\text{–}d\\ A\,A_2\text{–}A\,A_2\text{–}A\,A_2\text{–}4\text{–}F_2\text{–}F_2\text{–}F_2\text{–}F_2\text{–}E_2\end{array}\right\}\text{–}G$$

On notch *7*, the second section of resistance is cut out, and on notch *8* all the resistance is short-circuited and the motors run with full field strength. On the last notch, the fields are shunted. Fig. 32 is a diagram of the controller top showing how the notches are indicated. Each of the raised ribs *1*, *2*, *3*, etc. corresponds to a notch, and the running notches *4*, *5*, *8*, and *9* are indicated by ribs longer than *1*, *2*, *3*, *6*, and *7*, which represent the resistance notches. Both the operating handle H and the reverse handle K are shown at the off-position. The connections at the controllers must be made so that the car will run forwards when K is thrown to the ahead-position. It will be noted in Fig. 31 that the armature wires are interchanged in the two controllers; for

example, the wire connecting to post *A A*₁ in No. *1* controller connects to post A_1 in No. *2* controller. If this were not done, the movement of the car would agree with the direction in which the reverse handle pointed when operated from one controller but would not agree when operated from the other. Also, since the motors are mounted back to back on the truck, they must run in opposite directions when viewed, say, from the commutator end, in order that they may both propel the car in the same direction. In Fig. 31 the connections are such that the current flows through both armatures in the same direction, but the direction through No. *2* field is opposite to that through No. *1* field, and No. *2*

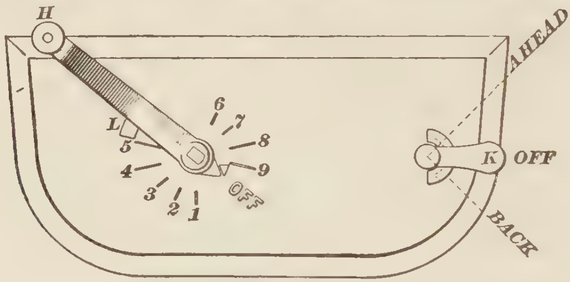


FIG. 32

motor would therefore run in a direction opposite to No. *2* when viewed from the same end. The usual method is to connect up the motors and turn on the current; if it is found that one or more of the motors are trying to drive the car in the wrong direction, they can easily be reversed by interchanging the field terminals. Fig. 33 shows diagrammatically the various combinations corresponding to the different controller positions; *S*, *S* represent the shunts across the fields and positions *4*, *5* and *11*, *12* are the only ones that should be used for steady running. The others are provided to prevent a rush of current at starting and when changing from series to parallel; also, to give a smooth acceleration.

63. Motor Cut-Out Switches.—In the lower part of the K2 controller, just below the power cylinder, the two motor cut-out switches are located. These are seen at 7, 7,

Fig. 30, and are marked No. *1* and No. *2* in Fig. 31. As mentioned before, the two motor cut-out switches are used to run the car on one motor if the other motor or any part of its circuit gives out. These two switches may be thrown up or down, and when the car is in good shape and both motors in use, both switches should be down, as indicated by the

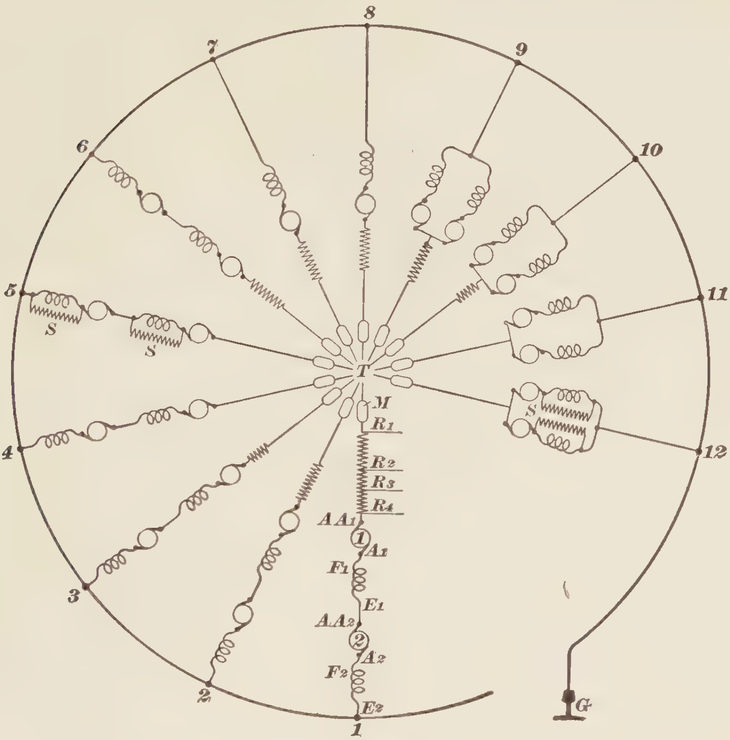


Fig. 33

connecting lines in Fig. 31. When No. *1* switch is thrown up, posts *19* and E_1 are connected together by casting *S*. Assuming that the controller is on the first notch, the path of the current beginning at point *t* is: t–19–S–E_1–E_1–E_1–c–15–15–15–15–3–A_2–A_2, etc. No. *1* motor is cut out and the current flows through No. *2* motor to ground. If No. *2* switch is thrown up, No. *1* being down, the current on

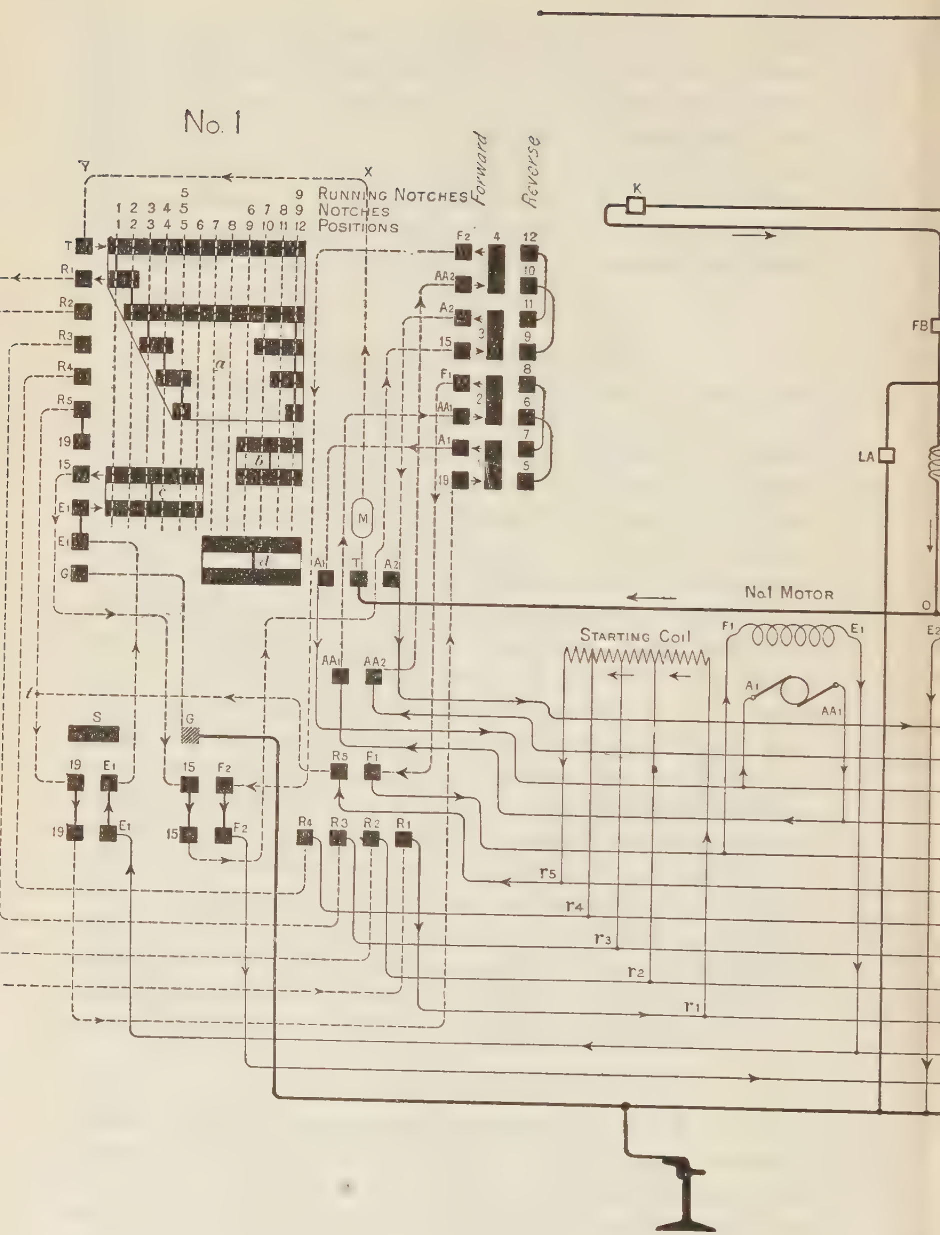
reaching post *15* on No. *2* switch goes directly to ground post *G* and No. *2* motor is cut out. When either of these switches is used, it operates an interlocking device that interferes with a collar on the power-cylinder shaft and prevents the cylinder from being moved beyond the last series position. It is obvious that if one motor is disabled it cannot be connected in parallel with a good motor, hence the necessity of the interlocking device to prevent the use of the parallel notches on type K controllers.

K10 AND K11 CONTROLLERS

64. The **K10 controller** is designed for the same class of work as the K2 and has largely superseded the latter. It is the standard controller for two-motor equipments where the motors are not over 40 horsepower. In general appearance, it resembles the K2 very closely but it has eleven contact fingers for the main cylinder against twelve on the K2. The K10 controller is designed for use without field shunts, thus eliminating the two shunt contact fingers. It has, however, an additional resistance finger and there are four sections in the starting resistance; the acceleration is therefore more gradual than with the K2 controller. The **K11 controller** is practically the same as the K10, but has heavier contacts so as to carry the current for two 60-horsepower motors. The diagram, Fig. 34, may therefore be taken as applying to both controllers, the arrowheads representing the path of the current on the first notch. Fig. 35 shows the combinations effected on the various notches. On account of the omission of the shunts, there are only two running notches, one (corresponding to position *5*) where the motors are in series with all resistance cut out and the other (position *12*) where they are in parallel with all resistance cut out.

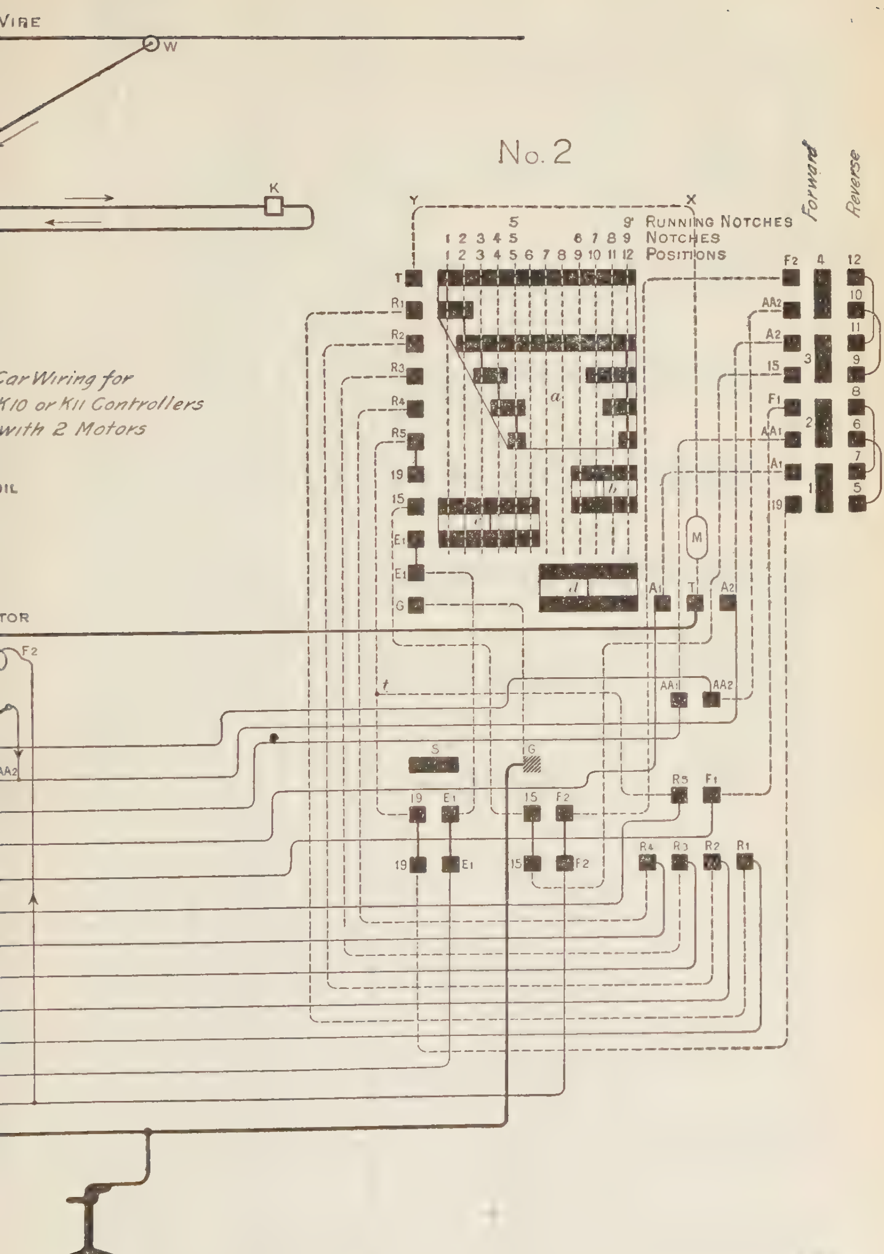
K12 CONTROLLER

65. The **K12 controller** is similar to the K11, but is arranged for the control of four 30-horsepower motors. Fig. 36 shows the general layout of the wiring for a car equipped with four motors and K12 controllers. The



No. 1
RUNNING NOTCHES
NOTCHES
POSITIONS
Forward
Reverse
STARTING COIL
No1 MOTOR

FIG.



Car Wiring for
K10 or K11 Controllers
with 2 Motors

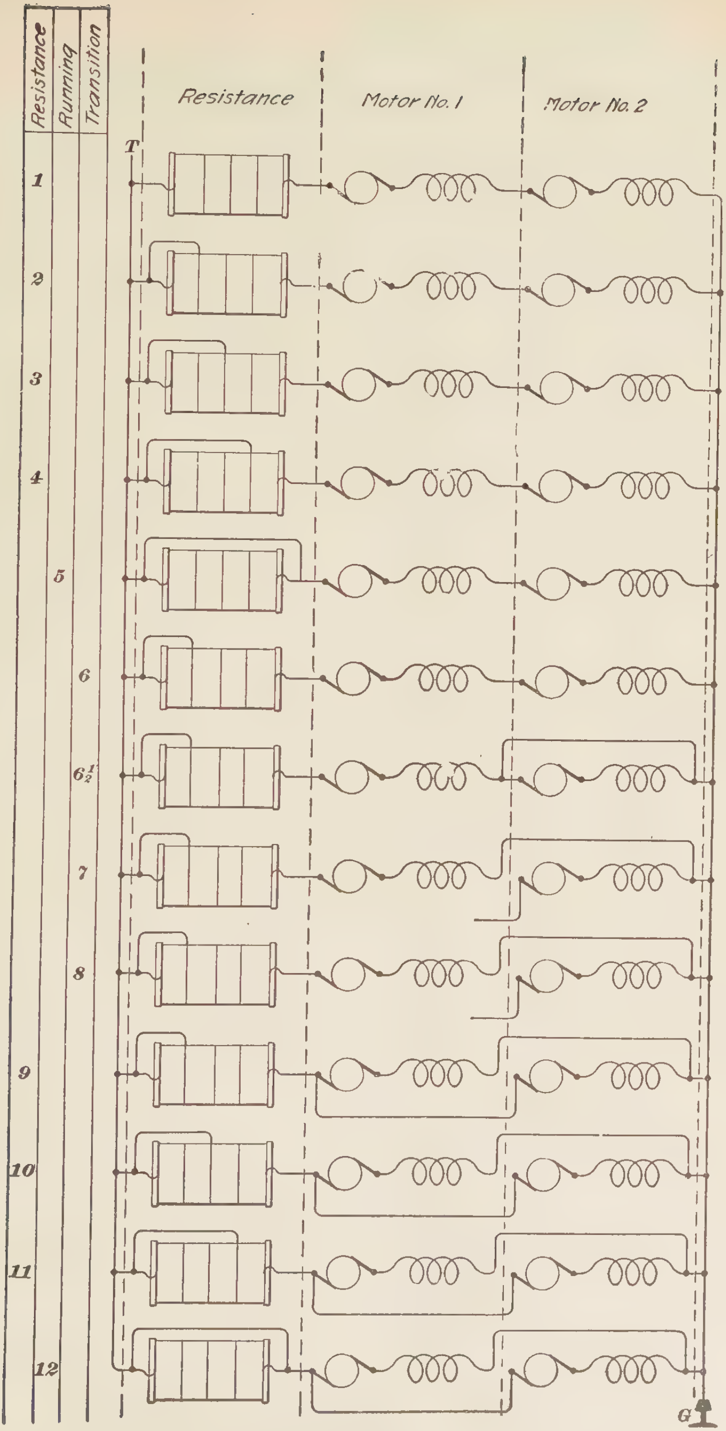

Resistance
Running
Transition
Resistance
Motor No. 1
Motor No. 2
T
1
2
3
4
5
6
6½
7
8
9
10
11
12
G

FIG. 35

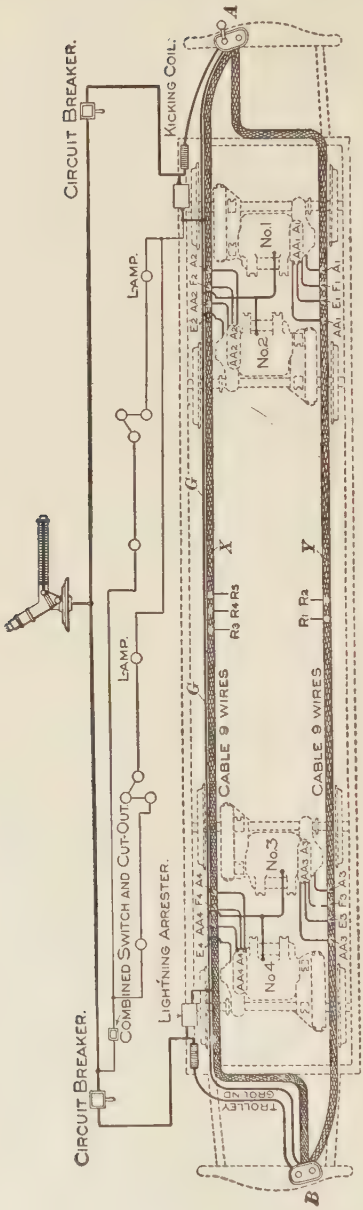


FIG. 36

motors, *1*, *2*, *3*, and *4*, are mounted back to back, two on each truck. The resistance coils are mounted under the middle of the car and are connected to the taps R_1, R_2, R_3, R_4, R_5. The two controllers *A* and *B*, the resistance coils, and the motors are connected together by wires run in the cables *X* and *Y*, or in conduit. *G G* is the ground wire, which is run separately and connected to the frames of all four motors, as shown in the figure. One end of the fields of motors No. *2* and No. *4* is also tapped to the ground wire.

The usual method for controlling a four-motor equipment is to connect the motors in pairs in parallel and then to treat the two pairs as if they were single motors, operating them by the series-parallel method, as with a regular two-motor equipment. This will be understood by referring to Fig. 37, which shows the various combinations effected by the K12 controller.

By referring to Fig. 35, it will be seen that the

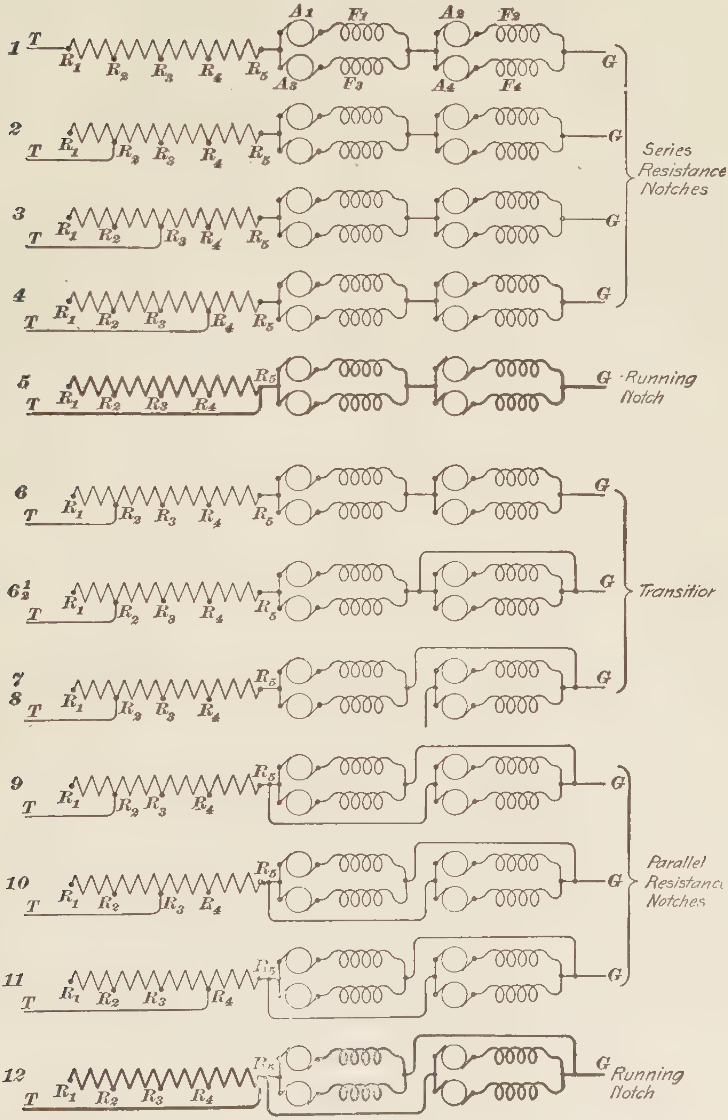

Series
Resistance
Notches
Running
Notch
Transition
Parallel
Resistance
Notches
Running
Notch

FIG. 37

combinations in Fig. 37 are practically the same as for the K11 controller, except that there are four motors in two pairs instead of the two single motors; No. *1* motor is connected in parallel with No. *3*, and No. *2* with No. *4*, so that a motor on one truck is connected in parallel with a motor on the other (see Fig. 36). There are two running notches, *5* and *9*, corresponding to controller positions *5* and *12*.

66. Fig. 38 is a car-wiring diagram for K12 controllers with four motors. The power cylinder is practically the same as that of the K11 but the reverse switch is different, being provided with a double row of contact fingers so that the current in all four armatures can be reversed when the car is to be run in the reverse direction. When the car runs ahead, reverse-switch fingers b are in contact with plates a and fingers d are in contact with c. When the car runs back, fingers b make contact with c and d with e, thus reversing the current in all four armatures. The leads E_2 and E_4 from the No. *2* and No. *4* motor fields are permanently connected to the ground wire. The main trolley wire connects to the blow-out coil, as shown. The path of the current on the first notch is indicated by the arrows and is as follows, starting from post T at the power cylinder: $T–R_1–R_1–R_1$, through all resistance, $–R_5–R_5–19–$

$$\left\{\begin{array}{c} 19–A_1–A_1–A_1–A\,A_1–A\,A_1–A\,A_1–F_1–F_1–F_1–E_1–E_1–E_1–3 \\ 19'–A_3–A_3–AA_3–AA_3–F_3–F_3–E_3–E_3–E_3–3 \end{array}\right\}–$$

$$15–15–\left\{\begin{array}{c} 15–A_2–A_2–A_2–A\,A_2–A\,A_2–A\,A_2–F_2–F_2–F_2–E_2 \\ 15–15'–A_4–A_4–A\,A_4–A\,A_4–F_4–F_4–E_4 \end{array}\right\}–G$$

The other combinations are indicated by Fig. 37, and may be easily traced out on the diagram. When the cut-out switches are operated, the motors are cut out in pairs; for example, if something goes wrong with the No. *1* motor and the cut-out switch is thrown up, motors No. *1* and No. *3* are cut out.

K6 CONTROLLER

67. The **K6 controller** is of larger capacity than the K12 and is intended for the control of four 40-horsepower motors or two 80-horsepower. In its general construction it is

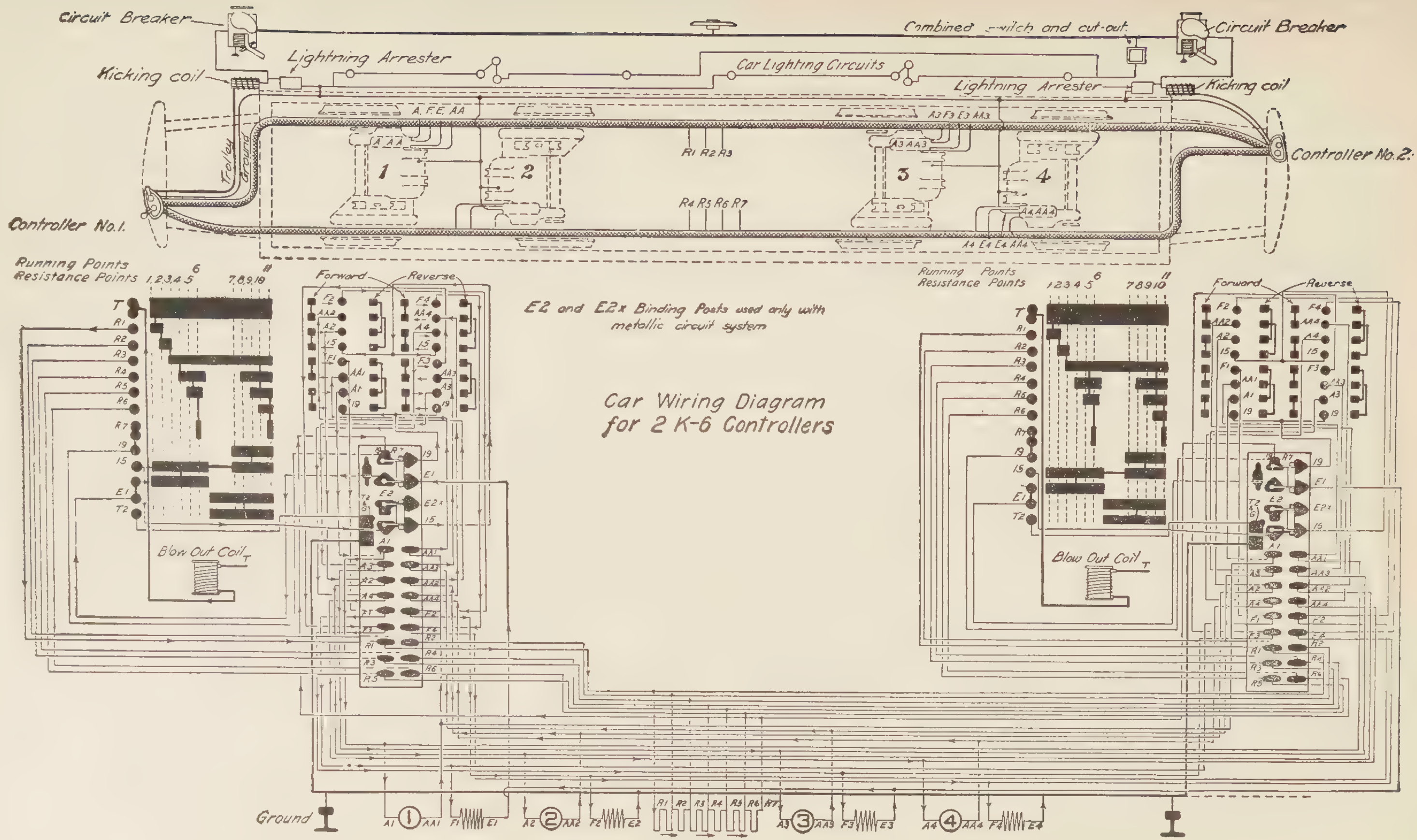

Circuit Breaker
Combined switch and cut-out.
Circuit Breaker
Lightning Arrester
Car Lighting Circuits
Lightning Arrester
Kicking coil
Kicking coil
Trolley
Ground
Controller No. 1.
Controller No. 2.
Running Points
Resistance Points
Forward
Reverse
Running Points
Resistance Points
Forward
Reverse
E2 and E2x Binding Posts used only with metallic circuit system
Car Wiring Diagram
for 2 K-6 Controllers
Blow Out Coil
Blow Out Coil
Ground

FIG. 39

similar to the K12 but the main cylinder and contact fingers are heavier. The pole piece carrying the arc guards is also arranged differently and the blow-out coil is in the bottom of the controller, the connection board being arranged vertically at the right-hand side. The reverse cylinder has four rows of segments mounted on it and there are two rows of contact fingers. Fig. 39 is a diagram of the car wiring showing the path of the current on the first notch. There are 11 notches, 6 of which are for the series connections and 5 for the parallel. When the reverse switch is on the forward position, the two rows of segments indicated by the arrows engage with the contact fingers, and when thrown to the other position the other sets of segments engage with the contact fingers, thus reversing the current in all four armatures. Motors No. *1* and No. *3*, No. *2* and No. *4* are connected permanently in parallel, the method of control being practically the same as was described for the K12 controller.

K14 CONTROLLER

68. The **K14 controller** is designed for the control of four 60-horsepower motors; it has seven series notches and six parallel, *7* and *13* being the two running notches. Since this controller has to carry quite a large current, its construction differs somewhat from the K controllers that have been described. Fig. 40 is a general view with the cover removed and the pole piece swung back. The main cylinder *a* is driven through gears *b*, *c* by the operating handle *d*, the angle turned through by the drum being greater than the angle through which the operating handle is turned from the on- to the off-position. The main cylinder rotates in a direction opposite to that on ordinary controllers; hence, the contact fingers are placed to the right of the cylinder. The reverse cylinder is at *e* and is operated by handle *f*; cylinders *e* and *a* are interlocked and handle *f* cannot be removed until both cylinders have been turned to the off-position. The trolley connection with the main cylinder is made at *g*, at the bottom of the cylinder, instead of at the top, as in the

controllers so far described. Instead of using a regular contact finger at *g*, contact is made with the cylinder by means of a split casting passing completely around a collar. This casting can be adjusted by nut *h*, so as to make a good contact without interfering with the movement of the cylinder, and it affords a better contact surface for the larger current than would be provided by a contact finger. The cut-out switches are located at *k*, *k* and are arranged in connection with an interlock to prevent the drum from being moved to the parallel position when either motor is cut out. This controller has no index wheel, but the notches are located by a hinged lever *m*, under the operating handle, that drops into notches, in an index *l* mounted on top of the controller. Lever *m* is raised so as to clear the notches, by the motorman pressing down on knob *n* on top of the operating handle. The controller has no connection board, the terminal wires being brought out of the bottom of the controller and fastened to the car wires by means of clamp terminals that are thoroughly taped over after the connections have been made.

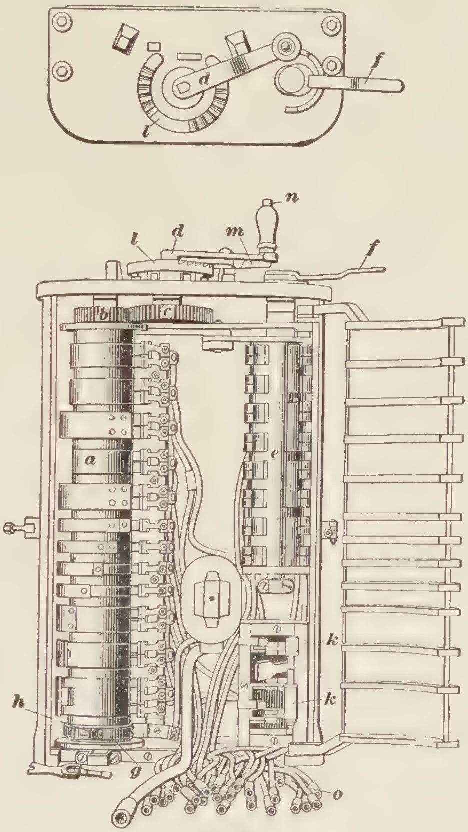
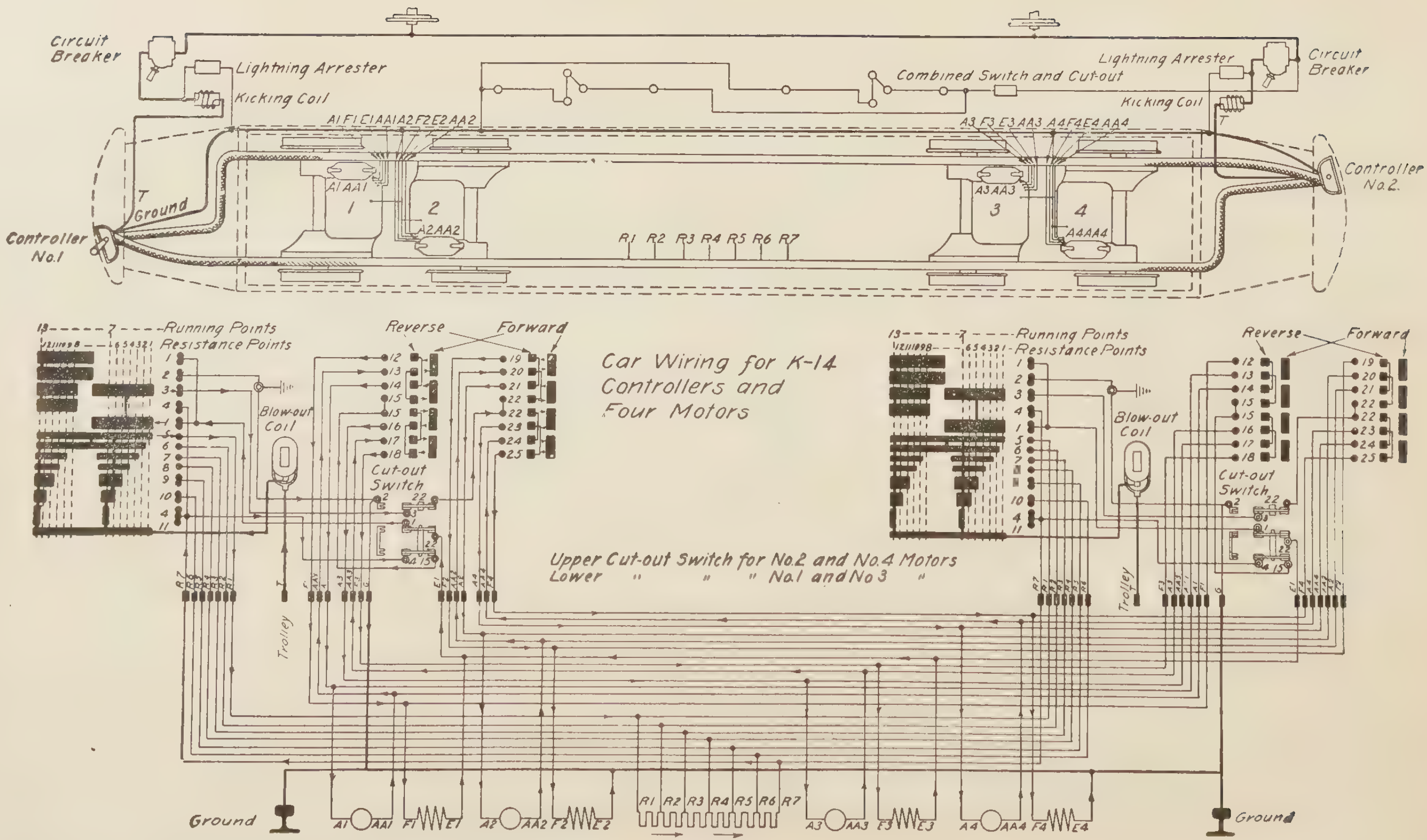


FIG. 40



Circuit Breaker
Lightning Arrester
Kicking Coil
Combined Switch and Cut-out
Lightning Arrester
Circuit Breaker
Kicking Coil
A1 F1 E1 AA1 A2 F2 E2 AA2
A3 F3 E3 AA3 A4 F4 E4 AA4
Controller No.1
Ground
Controller No.2.
R1 R2 R3 R4 R5 R6 R7
Running Points
Resistance Points
Reverse
Forward
Blow-out Coil
Cut-out Switch
Car Wiring for K-14 Controllers and Four Motors
Upper Cut-out Switch for No.2 and No.4 Motors
Lower " " " No.1 and No.3 "
Trolley
Ground

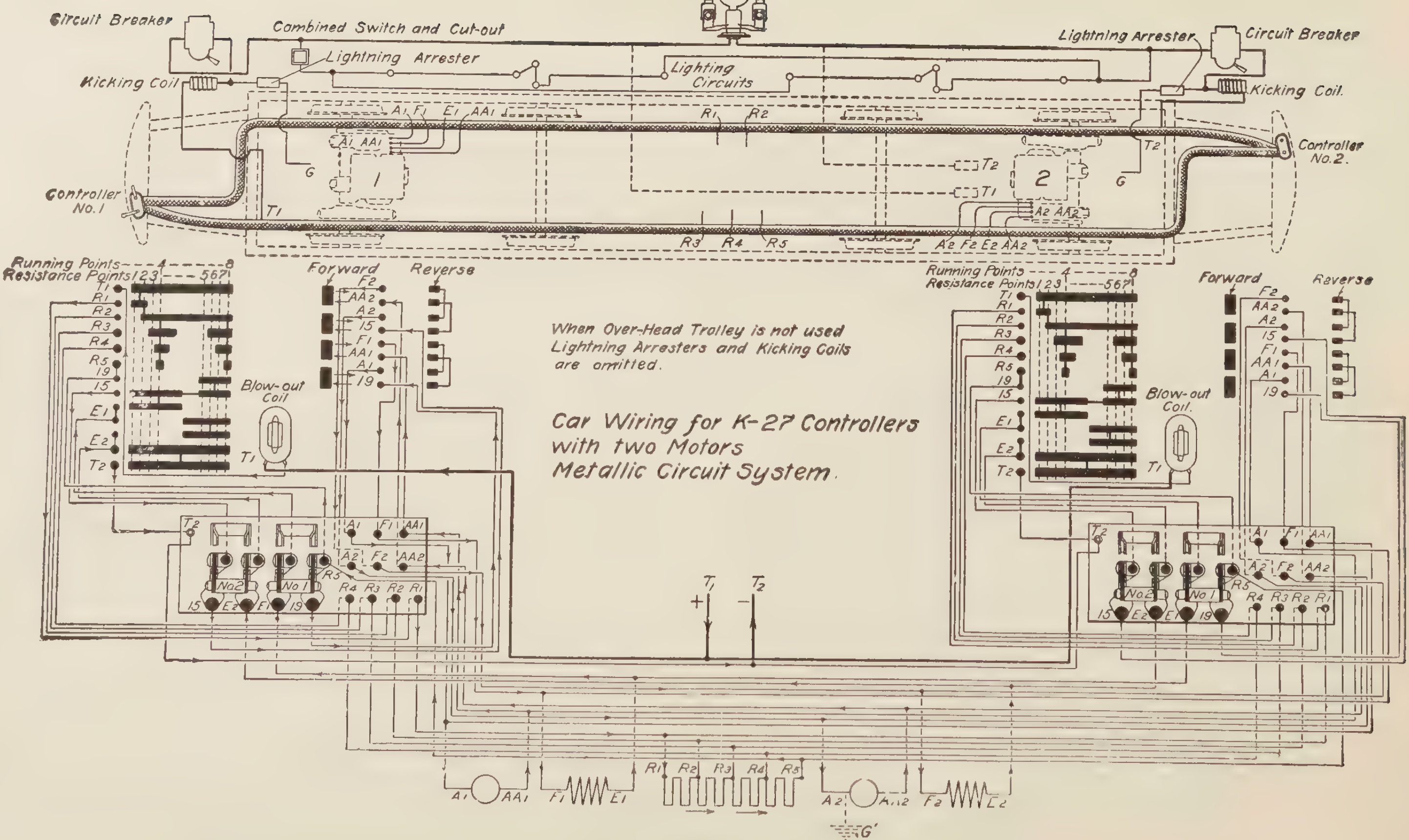
FIG. 41

Fig. 41 is a car-wiring diagram for K14 controllers with four motors, the path of the current on the first notch being indicated by the arrows. Motors *1* and *3*, and *2* and *4* are connected permanently in parallel.

K27 CONTROLLER

69. The **K27 controller,** for which Fig. 42 is a car-wiring diagram, is intended for use with two motors, not exceeding 60-horsepower, on metallic-return systems. It is used mostly on conduit systems, which are particularly liable to grounds, and on this account the controller contains a few features not found on ordinary K controllers. Any type K controller can be used for operating cars on a conduit system so long as both car and conductor rails are free from grounds; but should a car with a grounded connection run on to a section of conductor rail that is also grounded, conditions may arise where one of the motors would take current even with the controller thrown to the off-position, thus making the motorman lose control of the car and necessitating the opening of a circuit-breaker or hood switch in order to stop the car. The K27 cylinder is therefore designed so as to open both sides of the circuit when it is thrown to the off-position.

Suppose, for the present, in Fig. 42, that main cylinder fingers E_2 and T_2 are connected by a piece of wire. This will make the conditions the same as if an ordinary K10 controller were used, since with it, the end E_2 of the No. *2* field is connected to the negative, or ground side of the circuit, which with a metallic-return system corresponds to the T_2 terminal, or collecting shoe. Also suppose, in Fig. 42, that the A_2 brush, or a wire connected to it, becomes grounded as indicated by the dotted connection at G', and assume that the car runs on to a section where the conductor rail to which T_1 connects is grounded. Current can then flow from the positive conductor rail through the ground and enter No. *2* motor through the ground G' and flow through the path: $A_2 - A\,A_2 - A\,A_2 - A\,A_2 - F_2 - F_2 - F_2 - E_2$–post E_2 on controller. Now we have assumed E_2 and T_2 to be connected;



Circuit Breaker
Combined Switch and Cut-out
Lightning Arrester
Kicking Coil
Lighting Circuits
Lightning Arrester
Circuit Breaker
Kicking Coil.
Controller No. 1
Controller No. 2.
Running Points
Resistance Points
Forward
Reverse
Blow-out Coil
When Over-Head Trolley is not used
Lightning Arresters and Kicking Coils
are omitted.
Car Wiring for K-27 Controllers
with two Motors
Metallic Circuit System.

FIG. 42

hence, the current passes to T_2 and to the other conductor rail. Throwing the main cylinder to the off-position does not interrupt this current though a movement of the reverse switch would. In order to avoid this condition, the K27 controller is provided with fingers T_2 and E_2 so that the current must pass through the main cylinder, and hence throwing the cylinder to the off-position interrupts this current. Also, the E_2 field wire runs through the No. *2* cut-out switch, so that if this motor becomes grounded and is cut out by throwing up the No. *2* cut-out switch, all connections between the No. *2* field and the T_2 terminal will be broken. This is not possible with an ordinary type K controller where the end of No. *2* field runs directly to the ground wire without being brought to the controller.

70. The K6 controller, Fig. 39, can be arranged for use on metallic-return systems, by making a few changes in the connections. Instead of connecting the E_2 and E_4 field terminals to the ground wire (or T_2 wire on a metallic-return system), as indicated in Fig. 39, they are connected to a wire running to post E_2 on the connection board of, say, No. *1* controller. The ground wire, shown in Fig. 39, is connected to the T_2 collecting shoe, and a wire is run between posts E_2x on the two connecting boards. On the No. *2* connecting board, i. e., on the board to which the E_2 wire is not run, a connection is made between the E_2 post on the No. *2* cut-out switch, and the T_2 or G post. The object of these connections is to allow No. *2* and No. *4* fields to be disconnected from the T_2 side of the circuit in case of a ground, as explained in connection with Fig. 42. The K6 controller is not, however, arranged like the K27, so that the main cylinder will open both sides of the circuit and break any current that may flow through motors No. *2* or No. *4* because of grounds.

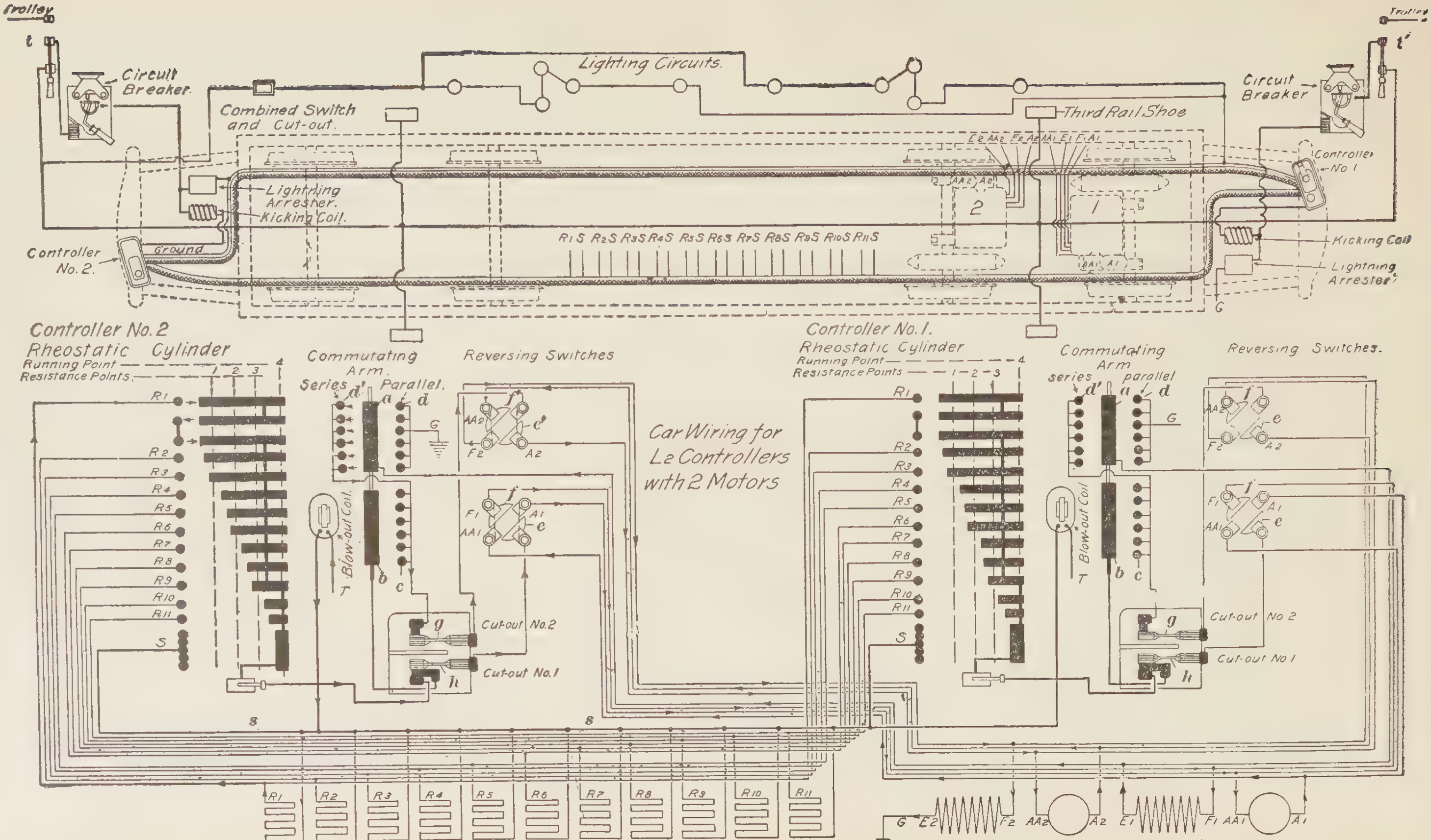
L2 CONTROLLER

71. The **L2 controller** is intended for heavy high-speed interurban cars and will control two 175-horsepower motors. On account of the large current, the main cylinder

contacts, and also any other contacts that have to carry the current while the motors are in operation, are made unusually large by connecting a number of fingers in parallel.

The L2 controller differs considerably from those of the K type, both in its construction and method of operation. The main cylinder simply cuts out the starting resistance and the changing over of connections from series to parallel is effected by a separate commutating arm or switch. While the commutating switch is changing from the series to the parallel position, the motor circuit is kept open by the main cylinder so that the commutating switch does not interrupt the current. Another feature is that the starting resistance is reduced by connecting resistance sections in parallel with the first section instead of cutting out sections, as in the K controllers.

72. Fig. 43 is a wiring diagram for L2 controllers as used on a car intended for operation either from an overhead trolley or from a third rail. Single-pole double-throw switches t, t' are provided in each vestibule, so that the main car wiring can be connected either to the overhead trolley or third rail. Thus, when the switches are thrown to the upper position, the car being supplied from an overhead trolley, the third-rail shoes are dead. There are two reverse switches on each controller, each serving to reverse the armature connections of one motor. The reverse switches are operated by a single handle at the side of the controller which when thrown to the ahead-position makes contact segments e, f, e', f' occupy the position indicated by the vertical dotted lines, thus connecting F_2 and $A A_2$, F_1 and $A A_1$, etc. When the reverse switch is moved to the back-position, segments e, f, e', f' are rotated so that contact is made between A_2 and F_2, A_1 and F_1, etc., thus reversing the current in the armatures. The main cylinder, shown at the left, cuts out the starting resistance. There are 4 notches for the series combinations and 4 for the parallel, the last notch on each being a running notch. To throw the controller from the off-position to the last series notch, the operating handle is turned through half a revolution, thus moving the main



Trolley
t
Circuit Breaker.
Combined Switch and Cut-out.
Lighting Circuits.
Third Rail Shoe
Trolley
t'
Circuit Breaker
Controller No 1
Lightning Arrester.
Kicking Coil.
Controller No. 2.
Ground
Kicking Coil
Lightning Arrester
R1S R2S R3S R4S R5S R6S R7S R8S R9S R10S R11S
Controller No. 2
Rheostatic Cylinder
Running Point
Resistance Points
Commutating Arm.
Series
Parallel.
Reversing Switches
Blow-out Coil.
Cut-out No. 2
Cut-out No. 1
Car Wiring for L2 Controllers with 2 Motors
Controller No. 1.
Rheostatic Cylinder
Running Point
Resistance Points
Commutating Arm
series
parallel
Reversing Switches.
Blow-out Coil
Cut-out No 2
Cut-out No 1
Rheostats
Motor No. 2
Motor No 1

FIG. 43

cylinder from the off-position to the position marked by the dotted line *4*. A further half revolution rotates the main cylinder backwards to the off-position so that when the handle has made a complete revolution and comes back to the starting point, the main circuit is again opened. As the handle is turned past the off-position, the commutating arm throws over to the parallel position before the main circuit is closed and, continuing the handle motion for another half revolution, the main cylinder again cuts out the resistance but this time with the motors in parallel. It thus takes a turn and a half of the operating handle to throw the power from the off-position to the last parallel position. The main drum is driven by means of a crank and sector-shaped gear, so as to give it a reciprocating motion, and the commutating arm is thrown from one side to the other by means of a cam, its movements being timed so that it opens or closes only when the current is cut off by the main cylinder. The commutating arm in Fig. 43 is represented by the segments a, b, insulated from each other and mounted so that, on the series positions a is in contact with fingers d'; on the parallel positions, a and b swing over so as to make contact with fingers d and c.

73. There are twelve series and parallel positions of the controller but only 4 notches on each; the path of the current on the first position is shown by arrows in Fig. 43 and is as follows: T–common resistance wire S–R_1–finger R_1–main cylinder–through cut-out switch No. 1–e–A_1–A A_1–A_1–A A_1–f–F_1–F_1–E_1–segment a on commutating arm–fingers d' (since the commutating arm is now in the series position)–cut-out switch No. 2–e'–A_2–A A_2–A_2–A A_2–f'–F_2–F_2–E_2–ground. When the controller is moved to the next position, section R_2 of the resistance is connected in parallel with R_1, thereby reducing the total resistance in series with the motors. On the third position, or first series notch, there are three sections of resistance in parallel; finally on the last series notch, fingers S make contact with the main cylinder, thereby short-circuiting all the resistance. The operating handle has by this time made half a revolution, and as it is moved

quickly around for another half revolution, the main cylinder reverses its motion, thereby cutting the resistance back in, and finally opening the circuit. Just as the operating handle begins its second revolution the commutating switch throws over so that *a* makes contact with *d* and *b* with *c*, the path of the current on the first parallel position being: $T\text{–}S\text{–}R_1\text{–}R_1\text{–}$main cylinder–cut-out No. *1*–

$$\left.\begin{cases} e\text{–}A_1\text{–}A\;A_1\text{–}A_1\text{–}A\;A_1\text{–}f\text{–}F_1\text{–}F_1\text{–}E_1\text{–}a\text{–}d \\ b\text{–}c\text{–cut-out No. }2\text{–}e'\text{–}A_2\text{–}A\;A_2\text{–}A_2\text{–}A\;A_2\text{–}f'\text{–}F_2\text{–}F_2\text{–}E_2 \end{cases}\right\}\text{–}G$$

As the motion of the operating handle is continued for another half revolution, the main cylinder repeats the resistance combinations that it made during the first half revolution, and when the last parallel notch is reached, the resistance is short-circuited by fingers *S* again making contact with the main cylinder. Fig. 44 shows the combinations made on each of the series and parallel notches.

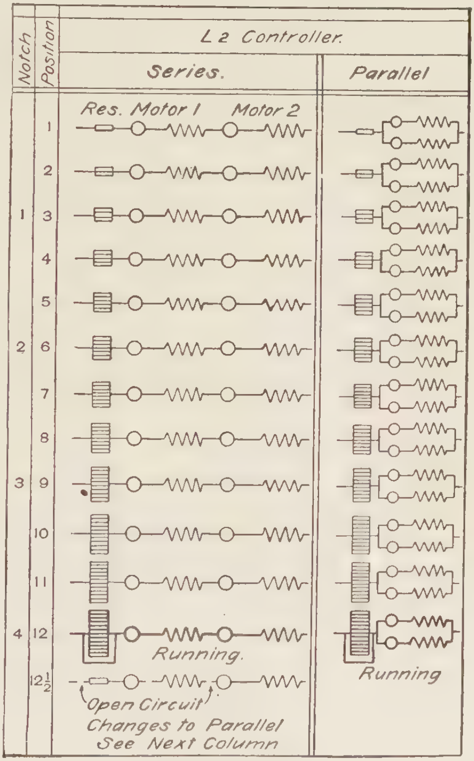


Fig. 44

74. Cut-Out Switches.—The cut-out switches simply open the circuit through the defective motor and if either motor is cut out, the commutating arm must be in the parallel position or there will be an open circuit. Thus, if motor

No. *1* is defective, it is cut out by opening switch blade *h*, and the controller is run on the last half revolution of the operating handle, in which case the commutating switch is on the parallel position and the current can take the path from cut-out No. *1*–*b*–*c*–No. *2* reverse switch and No. *2* motor to ground.

L4 CONTROLLER

75. The **L4 controller** is similar to the L2 but is provided with four reverse switches, the controller being designed for operating four 100-horsepower motors. The cut-out switches are also slightly different, but the main cylinder and commutating arm are the same. Motors No. *1* and No. *3*, No. *2* and No. *4* are connected in parallel and the two groups operated in series or parallel as with single motors. Fig. 45 shows the connections for a single L4 controller, which are so nearly like those of Fig. 43 that it will not be necessary to explain them in detail.

CONTROL OF ALTERNATING-CURRENT MOTORS

76. Alternating-current motors are specially adapted to interurban roads where the current has to be transmitted a considerable distance; hence, a high trolley pressure is used. This is stepped down by a transformer carried on the car so that the current supplied to the motors is at low pressure. It is frequently desirable to have the controlling apparatus arranged so that the cars can operate on either direct or alternating current, in which case switches must be provided for cutting out the transformer and making any other changes in connections that may be necessary. An arrangement of this kind allows interurban cars, that are normally operated by alternating current, to run over the tracks of connecting city roads operated by direct current.

77. Westinghouse Control.—Where a car is operated exclusively by alternating current, the speed of the motors can be regulated by varying the pressure, applied to the motors, by means of a potential regulator, or for small

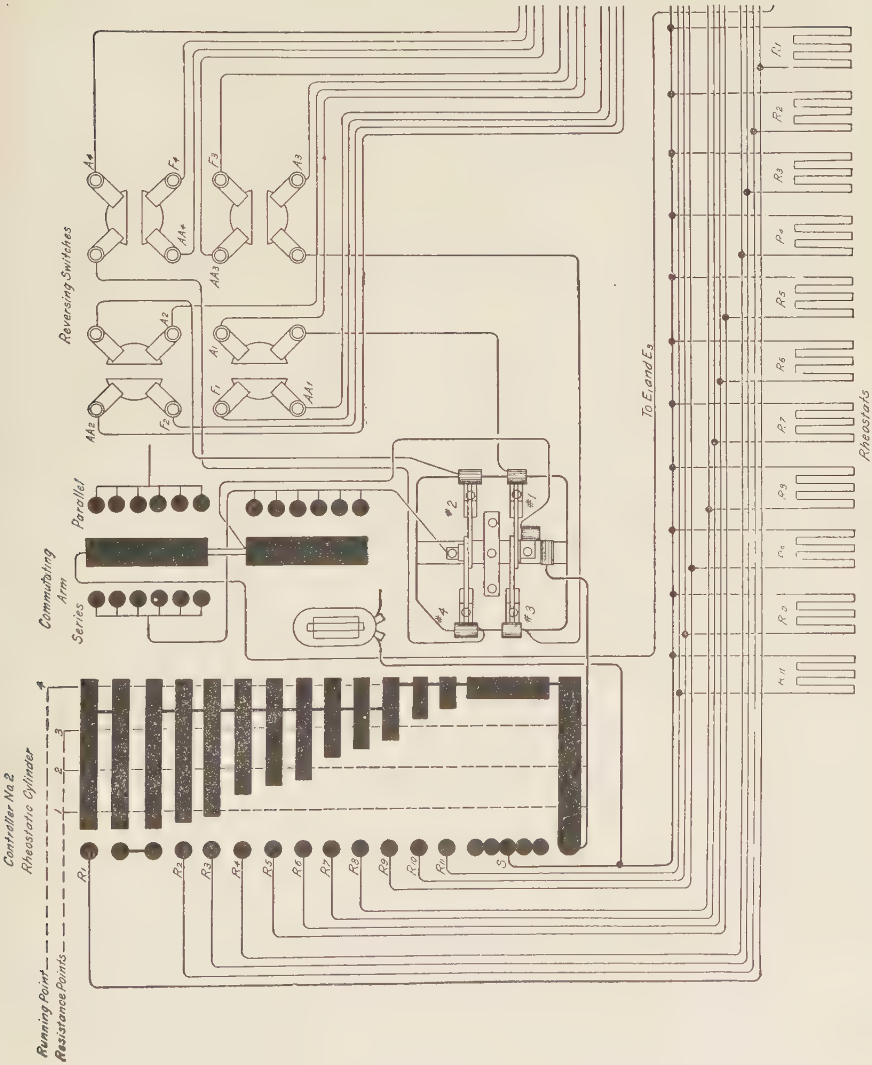
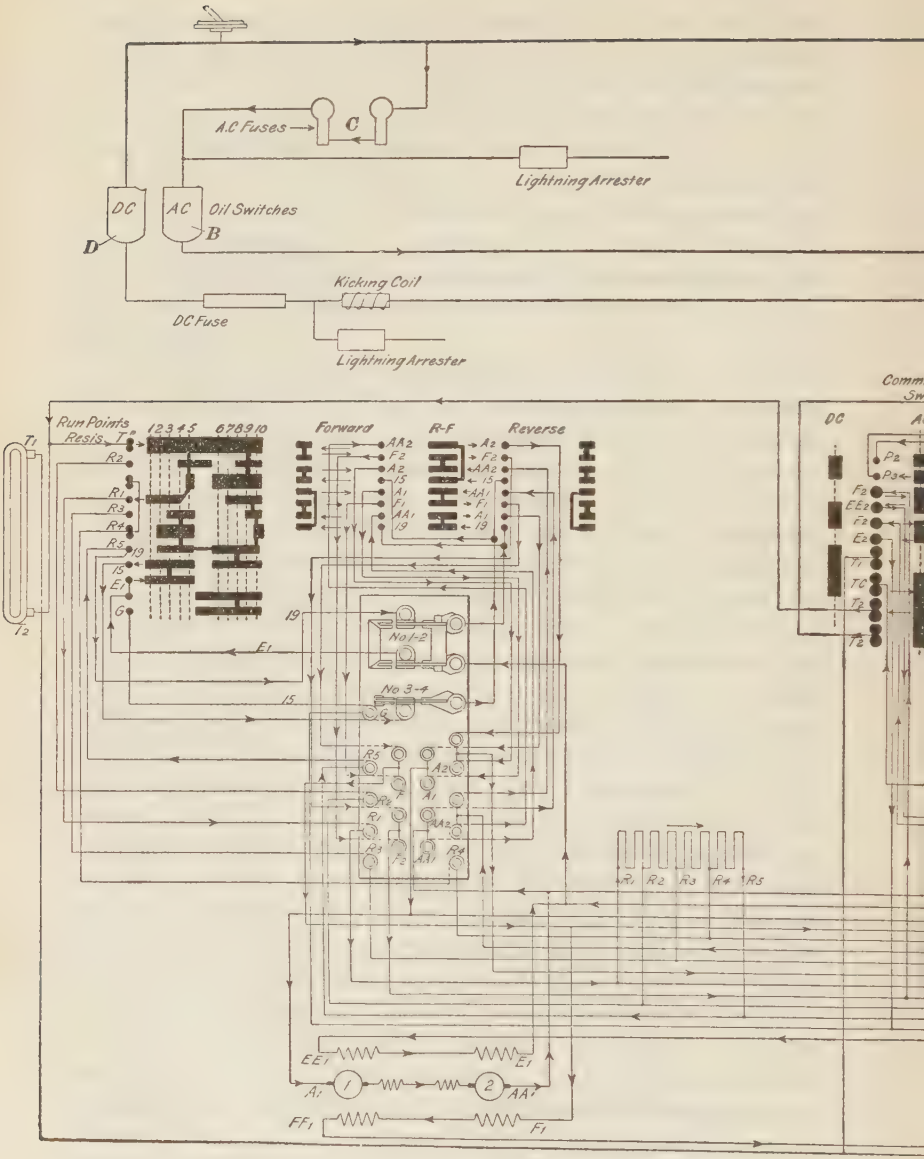

Reversing Switches
A4
F4
F3
A3
AA4
AA3
A2
A1
AA2
F2
F1
AA1
Parallel
Commutating Arm
Series
#1
#2
#3
#4
To E1 and E3
Controller No. 2
Rheostatic Cylinder
Running Point
Resistance Points
R1
R2
R3
R4
R5
R6
R7
R8
R9
R10
R11
S
Rheostats

Fig. 45

equipments, by providing the secondary of the step-down transformer with a number of taps that can be connected successively to the motor. This allows the applied pressure to be varied without the use of resistance and without the waste in power that resistance always causes.

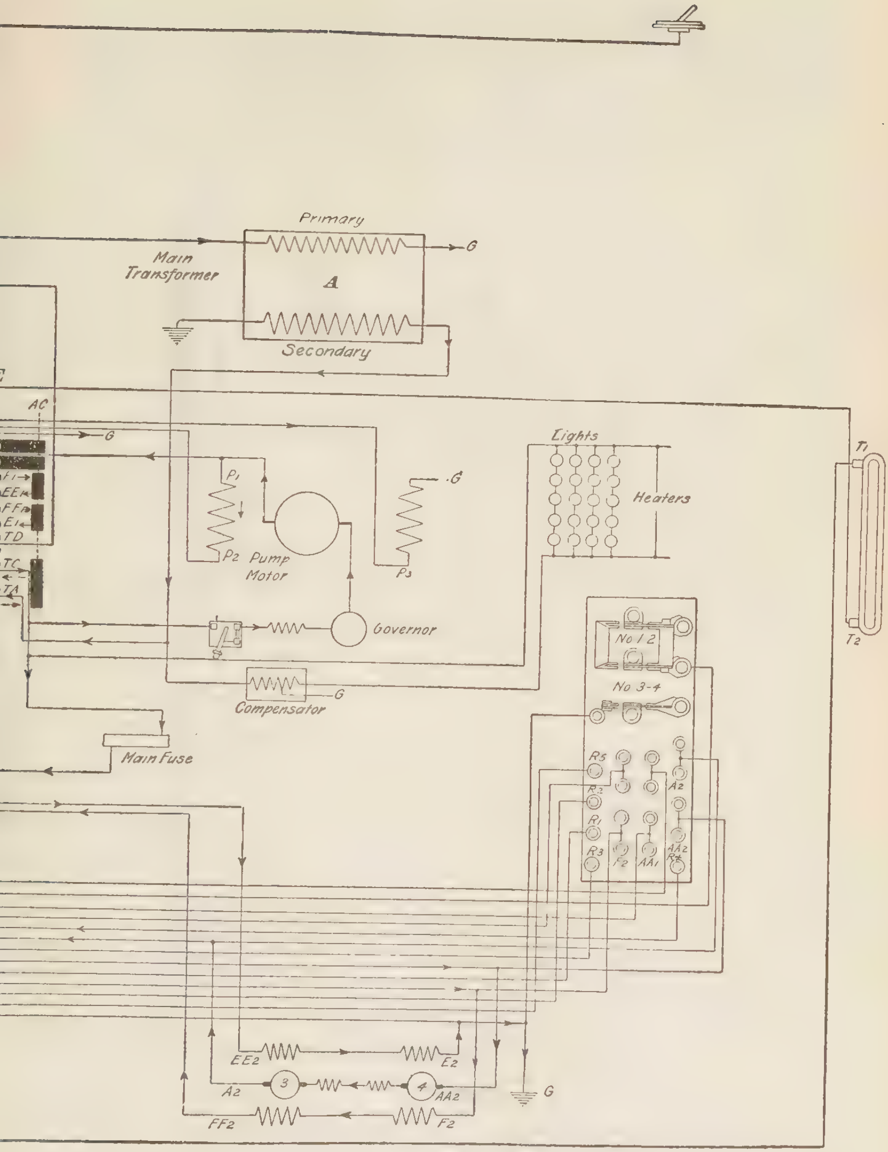
Moreover, every point of the controller is a running point and the car can be run steadily on any of the intermediate speeds, since there is no resistance to overheat. The voltage for which the motors are wound is independent of the line voltage, because the pressure can be stepped down to any desired value.

Fig. 46 (*a*) shows the general plan of operation for a large two-motor equipment where the speed is changed by means of a potential regulator. The current from the trolley passes through an autotransformer *a*, *b*, and from the secondary part *b* current is supplied to the motors. In some cases, a regular transformer with separate primary and secondary coils is used, especially if the trolley pressure is high and it is desired to completely separate the controlling apparatus and motors from the high tension line. The motors are wound for 250 volts and have their fields and armatures connected permanently in parallel, as shown; a reverse switch *e* allows the direction of the current through the fields to be changed, thus reversing the motion of the car. The potential regulator *c d* is of the induction type consisting of a fixed secondary *d* and a movable primary coil *c* that can be rotated through a limited range. The voltage generated in *d* can be added to or subtracted from the normal voltage of the transformer secondary, thus allowing the voltage applied to the motors to be varied gradually from 125 to 250 volts. The primary of the induction regulator is moved by compressed air supplied from the air-brake pump on the car, and controlled by electropneumatic valves. For small cars, the arrangement is as shown in Fig. 46 (*b*); instead of a potential regulator, the equipment is simplified by providing the transformer with a number of taps *1*, *2*, *3*, etc. to which terminal *d* can be connected successively by a platform controller, thus increasing the voltage applied to the motors.



A.C Fuses
C
Lightning Arrester
DC
AC
Oil Switches
B
D
Kicking Coil
DC Fuse
Lightning Arrester
Run Points
Resis.
1 2 3 4 5 6 7 8 9 10
Forward
R-F
Reverse
No 1-2
No 3-4
R1 R2 R3 R4 R5
EE1
E1
A1
AA1
FF1
F1
DC

F



Primary
Main Transformer
A
Secondary
AC
TD
TC
TA
Pump Motor
Governor
Compensator
Main Fuse
Lights
Heaters
No 1 2
No 3-4
R5
R1
R3
A2
AA2
F2
AA1
EE2
E2
FF2
3
4
G

78. General Electric Control.—Fig. 47 is a diagram of car wiring for the control of four General Electric compensated single-phase motors arranged so that the car can be run on either alternating current at 2,200 volts, or direct

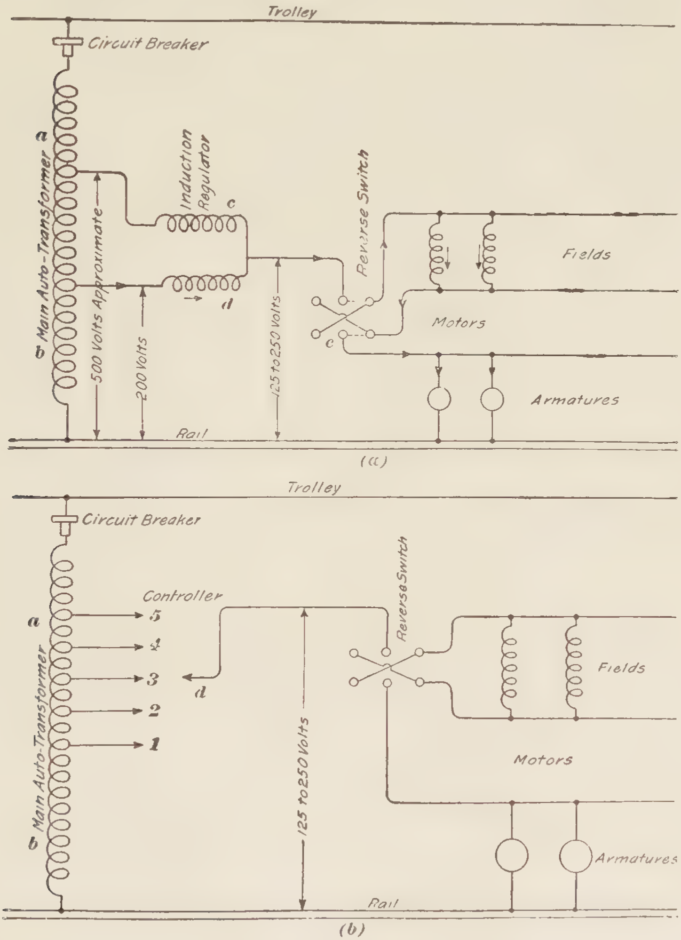


FIG. 46

current at 500 volts. On account of the use of direct current, resistance is used for the control of the motors, which are arranged in two pairs, two motors being connected

permanently in series for each pair. The regular series-parallel method of control is used and standard K28 controllers, as employed for the operation of direct-current cars, are connected to a separate commutating switch so that the connections can be changed from alternating current to direct current in a few seconds.

This scheme of control is not quite as economical as the potential-regulator method and does not give as many running speeds, but it has the advantage of using, for the most part, regular direct-current controlling apparatus, and the

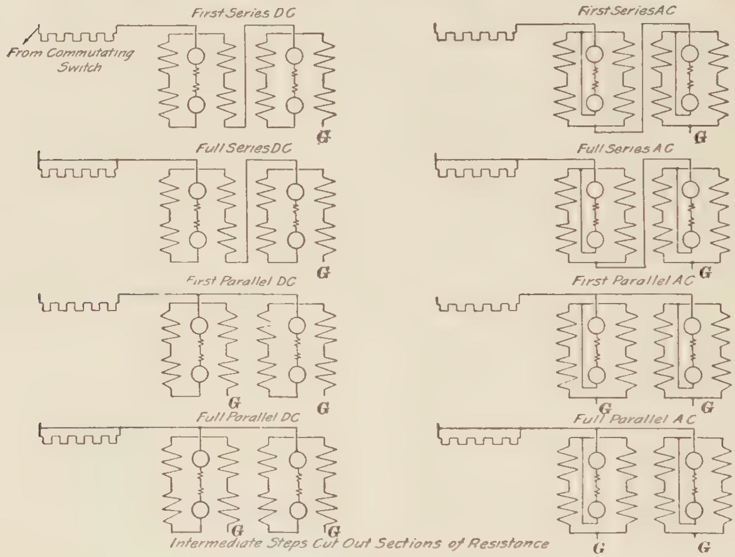


Fig. 48

additional apparatus required for alternating-current operation is small. The motors in Fig. 47 are wound for 200 volts alternating or 300 volts direct. *A* is the main step-down transformer for reducing the trolley pressure; in series with the primary are the oil switch *B* and fuses *C*. An oil switch *D* is placed in series with the direct-current connection also and both switches are interlocked with the commutating switch *E* so that the latter cannot be moved while either *B* or *D* is closed. The switches are also interlocked

so that only one switch can be closed at a time, thus precluding any possibility of trouble, on account of both currents being on at once. The commutating switch makes the necessary changes in field connections, and cuts out the step-down transformer, etc. when a change is made from alternating to direct and vice versa. In addition to the regular motors, the connections for the motor driving the air-brake pump are also shown, since this motor must likewise be changed over. In Fig. 47, the arrows represent the path of the current when the commutating switch is thrown to the *A C* position and the controller placed on the first notch.

In Fig. 48, the combinations on the most important positions for both direct and alternating current are given. With direct current, the four field coils on a given motor are in series, but when the change is made to alternating current the fields are connected two in series and the pairs placed in parallel. Also, when alternating current is used, it does not pass throughout the controller blow-out coil. The controller magnet core and pole pieces are not laminated; hence, alternating magnetism would cause heating.

ELECTRIC-CAR EQUIPMENT

MOTOR-CIRCUIT APPLIANCES

TRUNK CONNECTIONS

1. By **electric-car equipment** is meant the several appliances by means of which the car is propelled, controlled, heated, lighted, and protected, as well as the system of wires necessary to connect the electrical devices. Some car equipments are more elaborate and complicated than others, due to widely different conditions of operation. To illustrate: on level roads employing small cars that run around a belt or loop, the car equipment may consist of a single controller, two motors, and hand-brakes; on other roads, where cars made up into trains must be accelerated to full speed and stopped in minimum time, the unit equipment may consist of four heavy motors with automatic devices for controlling the motive power, an elaborate system of high-speed automatic air brakes supplemented with air signals, and the most modern appliances for heating and lighting by electricity. The following discussion will be limited to a consideration of the average modern equipment, operated under ordinary conditions.

2. The **trunk connections** have to do with the wires and devices traversed by the motor current in its passage from the current collector—trolley wheel, third-rail shoe, or conduit plow, as the case may be—to the point or points where the main control device receives it for application to the motor circuit in various combinations. The motor ground connections are sometimes considered as part of the trunk system.

TRUNK WIRE

3. The **trunk wire** is the wire part of the trunk connections, and takes its name from the fact that it conducts the total motor current of the car. It begins at the current collector and its path depends on the nature of the system on which the car is to be operated and on the location of the devices to be included. For example, Fig. 1 indicates the trunk wire on an ordinary surface car equipped with two hood switches and a fuse box; all devices are named and the current path is indicated by the order of the numbers. Fig. 2

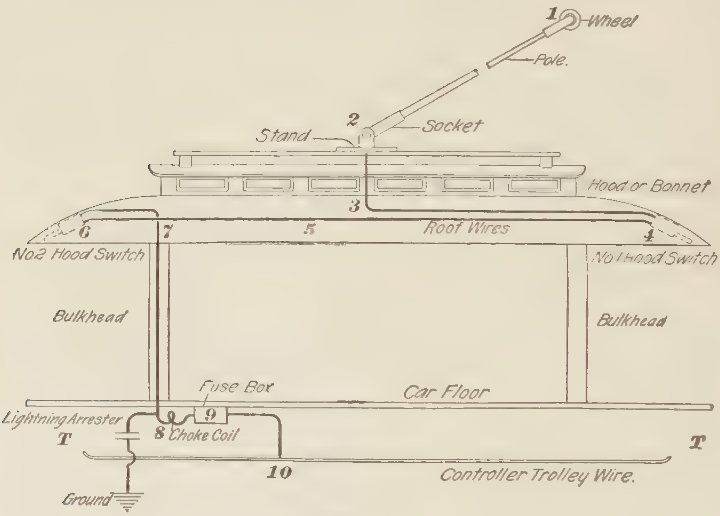


FIG. 1

shows the arrangement on cars intended to operate on both a third-rail and overhead ground-return system. The overhead construction includes two trolley stands, on opposite ends of the car, which may or may not be connected together; in either case a roof wire runs from each stand to a single-pole, double-throw, change-over switch in the vestibule or cab on that end. The third-rail construction consists of a spine wire running down the center of the under side of the car floor. The third-rail contact shoes on opposite sides of

the same truck are connected by a cross-wire that also connects to the spine wire, thereby connecting all four shoes together. A shoe is necessary on each side of each truck, because not only does the third rail contain gaps in places, but it frequently changes from one side of the track to the other. A car operating always from the same end on a road having a continuous contact rail always on the same side of the track would require but a single contact shoe. The continuation of the spine wire on both ends of the car is carried up through the bulkhead in some cases; in other cases, through metal conduit on the outside, to the other outside post of the change-over switch in the vestibule. From the handle post of the change-over switches the controller trunk wire runs to a circuit-breaker, located in the vestibule or under the car, and the other side of the circuit-breaker connects to the trolley post of the controller on that end. In some cases, a circuit-breaker or enclosed fuse is introduced in the spine-wire extension before it goes through the car floor, the idea being to have a safety device as near as possible to the contact shoes; but this idea is more often carried out by installing a fuse, called a *shoe fuse*, on the side of the truck above each contact shoe. The advantage gained by using the change-over switches is that the contact shoes of a car operating from the overhead wire are not alive. This is an important feature of safety at stations where passengers might come into contact with the third-rail shoes.

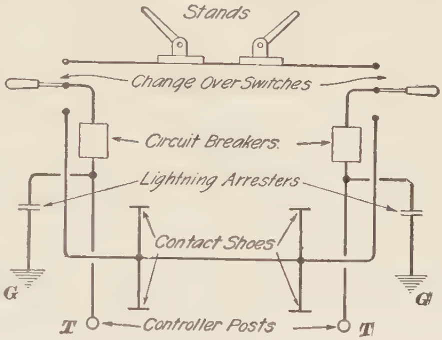


Fig. 2

4. Fig. 3 is a diagrammatic sketch of the trunk connections on a car equipped to operate on a conduit system. In this case, the trunk wire must traverse the distance from

the floor to the roof four times in order to reach the two overhead switches or circuit-breakers and return to the two controller trolley wires required in a metallic-return system. The bonnet switches are not necessary in this case, but are used to afford the motorman a convenient means of interrupting the current should the controller become disordered. On the open-conduit system, as operated in New York City, besides the motor switches installed in the bonnet there are installed under the car two circuit-breakers, two *ground switches*, so called because they were formerly the only means of cutting off the effect of grounds, and two fuses. All these devices are in series, so that the opening of any one of them will interrupt the current.

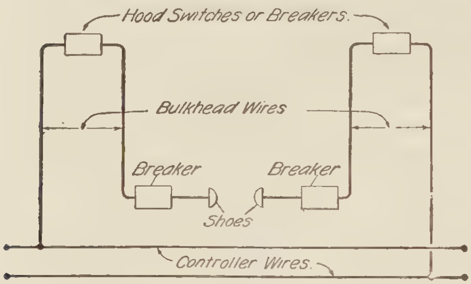


FIG. 3

OVERHEAD-TROLLEY FITTINGS

5. On ground-return overhead systems but one wire is used, so that short cars and long cars operating from the same end all the time require but one trolley device. Long cars that operate from both ends usually have two trolley devices, only one, however, being used at a time. On metallic-return overhead systems two trolley wires are used, thereby requiring a double, or duplicated, trolley device. On very long cars, there should be a double trolley device on both ends if the car operates from both ends.

The trolley device, or *trolley*, as it is commonly called, consists of a brass grooved *wheel* that turns on an axle supported in a suitable forked device, called a *harp*, that is riveted to the *trolley pole;* the pole being clamped in the *socket* of a *spring base* pivoted to a *foot* that is screwed to a board fastened to the car roof.

THE STAND

6. The Nuttal Stand.—Fig. 4 shows a type of trolley stand of which there are many in use. Base *a*, pivoted to foot *b*, which is let into the trolley board, carries an upright extension that serves as a bearing for axle *o*, around which socket *G* can rock in a vertical plane. Wings *f*, *f*, integral with the socket casting, engage tension rods *e*, *e*, of

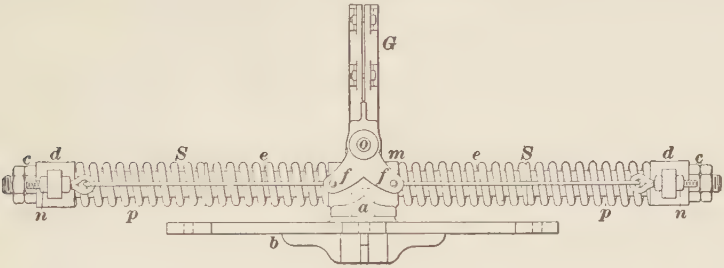


FIG. 4

which the other ends engage castings *d*. Movement of socket *G* in a clockwise direction will cause right-hand tension rod *e* to pull on its casting *d*, thereby compressing spring *S* mounted on right-hand arbor *p* and resisting the movement of the socket. Counter-clockwise movement of the

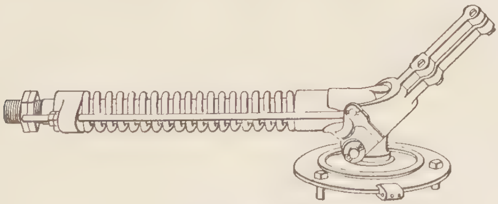


FIG. 5

socket will put the left-hand spring *S* into action. It follows, then, that if a pole under tension leaves the wire, the successive action of first one spring and then the other lessens the shock that the device would otherwise get.

7. The Union Stand.—Fig. 5 shows the union stand, which, having but one spring, cannot be rocked over. The

characteristic feature of this stand is that the same spring serves as a tension spring and as a recoil spring to take the shock when the wheel flies off the trolley wire.

POLE, HARP, AND WHEEL

8. Pole.—The pole proper, which is from 12 to 15 feet long, is about $1\frac{1}{2}$ inches in diameter at the large end, and

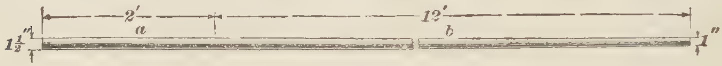


FIG. 6

holds this diameter for about 2 feet, when it tapers gradually to a diameter of 1 inch. Most poles are steel, hard drawn by a special process, and offer great resistance to bending. A slight bend in a pole is generally straightened by using a post with a hole in it as a vise and bending by hand; but severe bends should be taken out by sledging cold. A pole should not be heated to straighten it, as the character of the steel is generally such that the part heated becomes soft and easily bent. Fig. 6 gives an idea of the straight and tapered part of a standard pole.

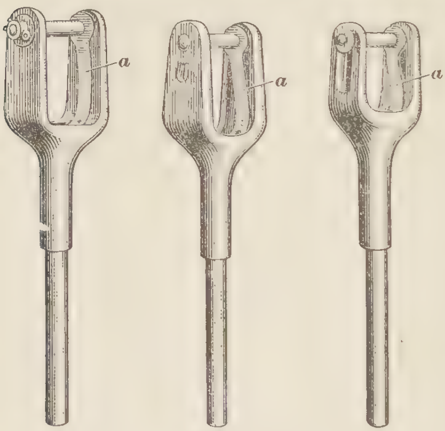


FIG. 7

9. Harp.—The harp in which the wheel turns is the forked device secured to the small end of the pole. Harps are made of malleable iron or brass and are of various sizes and shapes, depending on local conditions. Fig. 7 shows several styles of harp, all of which are provided with two springs *a*; the end of each spring bears against the side of the trolley wheel, thereby preventing the bearing surface

between the wheel and axle from carrying appreciable current. The main requirements of a harp are that it be as light as practicable and of smooth contour, to minimize the chances of its catching in the line work and pulling it down.

10. Wheel.—The trolley wheel is a device on which much experimenting has been done to determine the best shape of wheel and the best composition of metal consistent with long life of the wheel and trolley wire. Some wheels wear out more quickly than others, and some are harder on the trolley wire. A wheel that is too soft will wear out very soon; on the other hand, a wheel that is too hard or that has a poorly shaped groove will scrape the trolley wire at curves and turnouts. Almost all roads do a certain amount of experimenting to decide what shape and metal are best

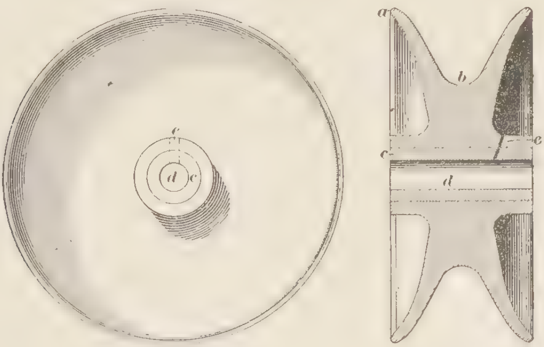


FIG. 8

adapted to the overhead construction. A good lesson can be learned from a careful observation of worn-out wheels; some wheels wear out most in one place and some in another; the same make and shape of wheel will wear differently on different branches of the same road.

Fig. 8 shows a type of wheel, of which *a* is the flange; *b*, the groove; *c*, the bushing or bearing; *d*, the hole through which the axle passes; and *e*, the hole for oiling. On the more modern types of trolley wheel, of which a number are shown in Fig. 9, the bearings are of the self-lubricating type.

The diameter of trolley wheels varies from 4 to 8 inches, according to the speed of the service, the most common size being about $4\frac{1}{2}$ inches in diameter. The last of the series of wheels shown in Fig. 9 is called a **sleet wheel**, because it is used to cut sleet off the wire. The wheel is cast with holes in the flanges and the machining of the grooves leaves the holes with sharp edges that cut the sleet. In the absence of a sleet wheel it is customary to remove the ordinary wheel and use the harp as a cutter.

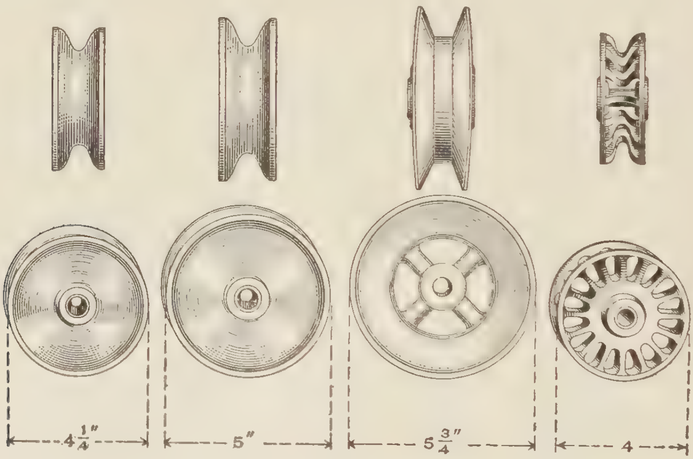


FIG. 9

11. Pressure of Wheel on Wire.—The pressure of the wheel against the trolley varies from 12 to 20 pounds, according to local conditions and the speed at which the car is to run. Too light a pressure will permit the wheel to jump off at kinks and turns, while excessive pressure will wear all parts unnecessarily and cause trouble in replacing a wheel that has jumped the wire. Under ordinary conditions, the pole should make an angle of about 45° with the car roof and the upward pressure on the wire should be about 15 pounds.

SWITCHES AND BREAKERS

SWITCHES

12. Remarks.—The motor switches used on cars to interrupt the motor circuit are of the same general type, whatever may be the nature of the system on which the car is to operate. On ground-return systems they are installed under the car hoods, and are called **hood switches.** In slotted conduit work the hood switches are also installed for reasons of safety, but in addition similar switches are installed under the car, as near as possible to the plow shoes.

13. Type of Switch.—Fig. 10 shows a motor switch in very general use; it is of the magnetic blow-out type.

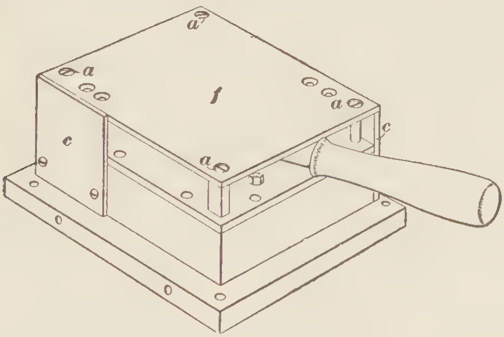


FIG. 10

Fig. 11 shows the top plate removed, exposing the connections. In Fig. 11, $e+$ is the roof wire leading to the switch and $e-$, that leading from it. The switch blade turns on pin p as a center, and M indicates the magnetic blow-out coil in the bottom of the case. Switch blade B is of iron and covers part of the magnetic circuit through which coil M sets up lines of force that pass across the current-breaking contacts. When the switch is closed, as in the figure, current enters at $e+$; to reach pin p, part of the current passes from the terminal jaw a through the switch blade, and part passes through coil M, which is of very low resistance. The

total current passes through the right-hand end of blade *B* to reach jaw *d*. On opening the switch, the instant jaw *a*

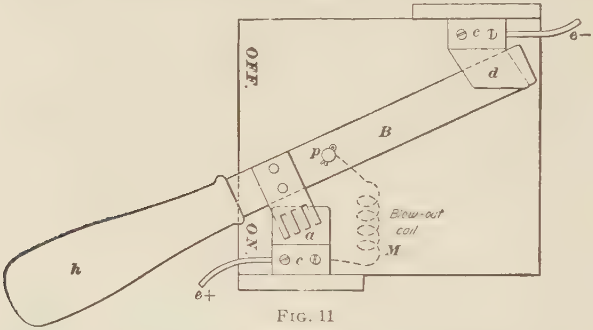


FIG. 11

breaks contact with the switch blade, the entire current must pass through blow-out coil *M*, thereby establishing a strong magnetic field that ruptures the arc at *d*.

CAR CIRCUIT-BREAKERS

14. In some cases, **circuit-breakers** have entirely replaced hood and ground switches; in others, one of the two hood switches has been replaced by a circuit-breaker; while in still others, two ground switches have been supplemented by two circuit-breakers connected in series with the switches and located alongside of them. All car circuit-breakers have facilities for operating them by hand, like a switch, and the only advantage of using a circuit-breaker and motor switch in series is to obtain the automatic safety feature of the breaker without buying two breakers. Car circuit-breakers should always be adjusted in the position that they are to occupy when on the car, otherwise gravity may introduce an error in the setting.

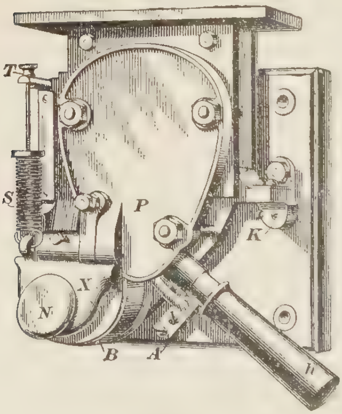


FIG. 12

15. General Electric Car Circuit-Breaker.—Fig. 12 shows a type of surface-car circuit-breaker made by the General Electric Company. When used as a hood breaker it is enclosed in a box from the front end of which the handle projects, as indicated in Fig. 13.

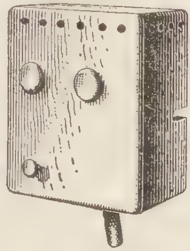


FIG. 13

In Fig. 12, A and K are the breaker terminals and B the operating coil, which also provides magnetism for extinguishing the arc. Coil B pulls armature X against spring S whenever the current exceeds that for which the breaker is set. The operating current value is adjusted by means of nut T. The iron

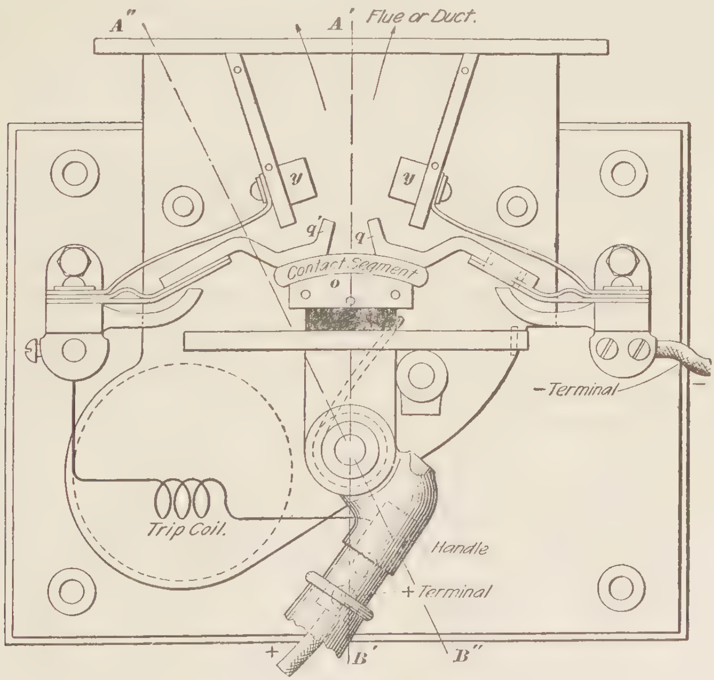


FIG. 11

plate P and a similar one back of it are magnetized by the current in coil B, and as the arc occurs between these two

poles, it is promptly extinguished by the magnetic field existing there.

Fig. 14 shows the movement of parts during operation of the breaker. The contact segment engages fingers q, q', so that the breaker is closed. When the breaker operates, the center of the contact segment o takes a position coinciding with line $A'' B''$, thereby leaving an open circuit between fingers q, q'. The arc is forced up by the magnetic field to auxiliary contacts y, y, between which it is broken without damage.

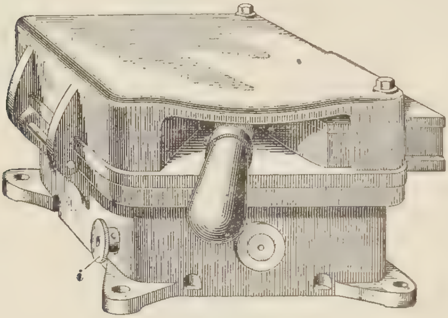


FIG. 15

16. Westinghouse Type of Car Circuit-Breaker. Fig. 15 is a general view of a surface-car breaker made by the Westinghouse Company. The screw for adjusting the operating current value is shown at i; this screw must be pulled out a little and turned while it is held out, in order to

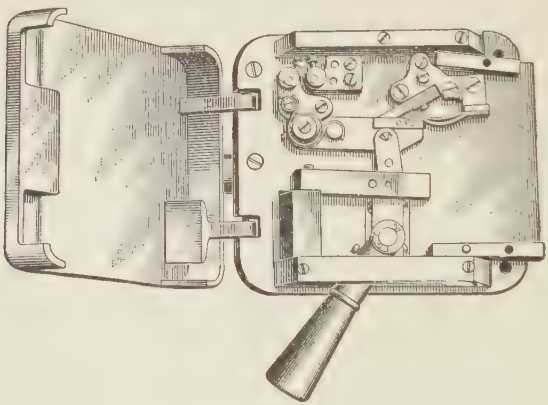


FIG. 16

adjust the tension on the spring that regulates the tripping point. Fig. 16 shows the breaker with the circuit-breaking parts exposed, and Fig. 17 indicates the movement of the circuit-breaking parts from the on- to the off-position. When handle *a* is to the left, the breaker is held closed, because spring *l* keeps togglejoint *c d* beyond the dead center, but no further than permitted by a projection on the under side of slide *f*.

To operate the breaker by hand, handle *a* must be forced to the right, thereby bending the togglejoint to the left and permitting spring *l* to snap blade *e* and all attached parts to the dotted position. Automatic operation is effected by an electromagnet, the coil of which is energized by the current and pulls armature *g* to the left, thereby bending the togglejoint to the left, as in the case of hand operation, whenever the current exceeds the value for which the breaker is set. The secondary contacts *o* and *p* are in parallel with the primary contacts *m*, *n* when the breaker is closed. When the breaker operates, *m* leaves *n* before *o* leaves *p*, thereby breaking the current at contacts *o* and *p*, which are cheap and easily replaced. The final break takes place in a powerful magnetic field that promptly extinguishes the arc.

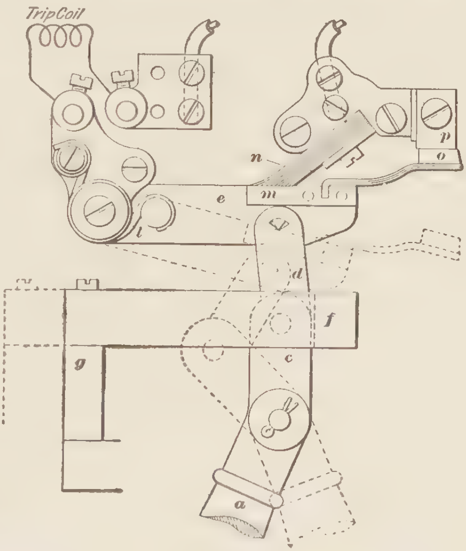


Fig. 17

FUSES

17. At one time, the **fuse** alone was used to protect motor circuits from excessive currents. On many roads, the circuit-breaker has superseded the fuse, because, for protection under given conditions, a circuit-breaker can be set to act at a closer overload value with a fair degree of certainty than a fuse; and in cases of operation, it is much easier and quicker to close a breaker than to replace a fuse. Circuit-breakers kept in proper repair and adjustment are certainly more reliable than fuses, from the protection point of view.

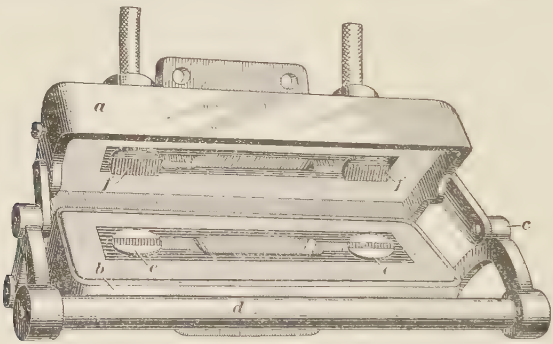


FIG. 18

On some large roads there seems to be a tendency to revert to the practice of using fuses, at least in conjunction with circuit-breakers, because in many cases of failure of the circuit-breaker the controller has blown up with disastrous results, as regards suits for damages. A circuit-breaker in series with a fuse is a good combination on a car, as the breaker is normally more of a protection than the fuse, but the fuse will prevent accidents should a short circuit occur and the breaker fail to operate because of being stuck.

WESTINGHOUSE CAR FUSE

18. Fig. 18 illustrates a type of fuse box introduced by the Westinghouse Company. The asbestos-lined iron box is divided into two parts *a* and *b*, hinged together through a

togglejointed construction *c* provided at the front with the handle bar *d*, the raising of which brings the two halves *a*, *b* together. In the bottom half are copper terminals with **V**-shaped grooves *c*, into which a piece of copper-wire fuse of suitable length is dropped. Registering with the **V**-shaped grooves *c*, *c* in the bottom terminals are **V**-shaped tongues *f*, *f* in the top terminals. On bringing the top and the bottom halves of the case together, by pulling up handle bar *d*, the two pairs of **V**-shaped jaws automatically clamp the fuse in circuit. The advantages of this type of fuse box are low maintenance cost and the care and quickness with which a fuse can be replaced without liability of shock; the lower terminals are dead when the case is open.

The size of copper wire to be used as a fuse to protect any equipment of given horsepower can be obtained as follows:

Rule.—*Multiply the total horsepower of the equipment by 70, and in the circular-mils column of any wire table find the nearest number to the product so obtained.*

EXAMPLE.—What size of copper wire must be used to protect an equipment of two 50-horsepower 500-volt railway motors?

SOLUTION.—The total horsepower of equipment is $2 \times 50 = 100$. $100 \times 70 = 7{,}000$. The nearest number to 7,000 in the circular-mils column of a B. & S. wire table is 6,529, which corresponds to a No. 12 B. & S. wire. Ans.

ENCLOSED FUSES

19. Figs. 19 and 20 illustrate fuses that, on account of the fuse metal being enclosed, are called **enclosed fuses.** The hollow cartridge *a*, Fig. 19, is made of some tough, fibrous, insulating material and is provided with copper heads or terminals *b*. The fuse metal occupies the hollow space, and its two ends connect to terminals *b*; the space surrounding the fuse is filled with finely divided powder, such as plaster of Paris mixed with powdered borax, which, when the fuse melts, fluxes with the molten metal, rendering it non-conducting and preventing the formation of an arc. The fuse as a whole is installed in spring jaws *c*, connected with terminals *d*, by means of which the fuse is connected

in the circuit to be protected. In Fig. 19, the parts are simply mounted on a slate base, but in Fig. 20 the whole device is enclosed in an asbestos-lined iron box *a*, provided with a lid *b* held closed by latch *c*. The trunk wire passes to

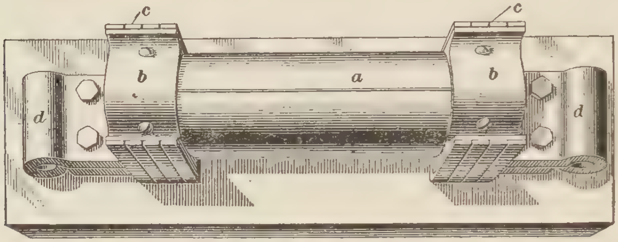


FIG. 19

fuse-block terminals *d* through hollow insulating bushings *e*. Some enclosed fuses, instead of having contacts to fit spring jaws, have ordinary eye terminals that must be secured to their seats with screws. The screw connection is probably

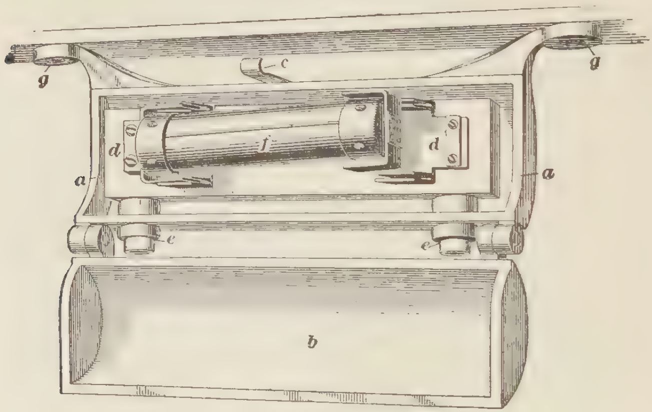


FIG. 20

more mechanical, but the spring-jaw construction is sufficiently safe and is much more convenient.

To tell whether or not the enclosed fuse is blown, a small wire *f*, called the *telltale*, is connected in parallel with the

enclosed fuse but on the outside of the cartridge. When the main fuse blows, the telltale burns out also. The enclosed type of fuse can be installed without danger of burn or shock, by taking hold of the cartridge at the middle.

LIGHTNING ARRESTERS

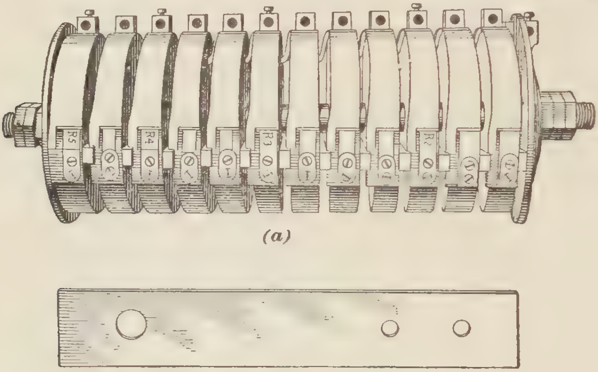
20. Lightning arresters used in car work are practically the same as many of the arresters described in a preceding section. A car arrester must have facilities for extinguishing the arc due to the line current following the lighting discharge across the gap. Owing to the jolting and vibration to which a car arrester is subjected, the spark points cannot be set for as thin an air gap as on a stationary arrester, because of their liability to jolt together and produce a short circuit. The arrester must be enclosed in a wooden box, which protects it from the mud and water slung by the car wheels.

On cars that operate entirely in a tunnel or on a conduit system, no arresters are needed on the car, but exposed line feeders are protected in the usual manner; this is also the case on elevated third-rail systems. On overhead metallic-return systems, both ends of the motor circuit must be protected by an arrester. On ordinary surface trolley cars but one arrester is used on the trolley end of the motor circuit; two would be better as a factor of safety should one get out of adjustment.

An arrester having parts depending on gravity for action should be installed vertically, otherwise it cannot work. Where an external choke coil is used, or an arrester has three terminals, one of which leads to an internal choke coil, care must be taken to connect the arrester so that the choke coil is in series with the motor circuit and not in series with the air gap.

RESISTANCE COILS

21. Westinghouse Starting Coil.—Fig. 21 illustrates a type of car **resistance coil**, or so-called **diverter**, made by the Westinghouse Company. It is of the well-known



(a)

(b)

Fig. 21

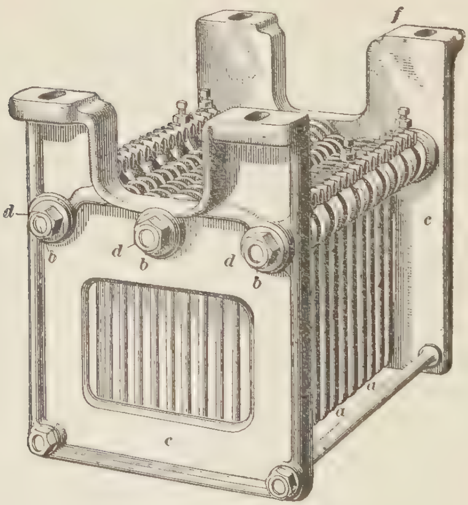


Fig. 22

barrel type wound with band iron, with mica insulation between layers. It is a decided improvement on older types in that the ventilation facilities are much better, on account of

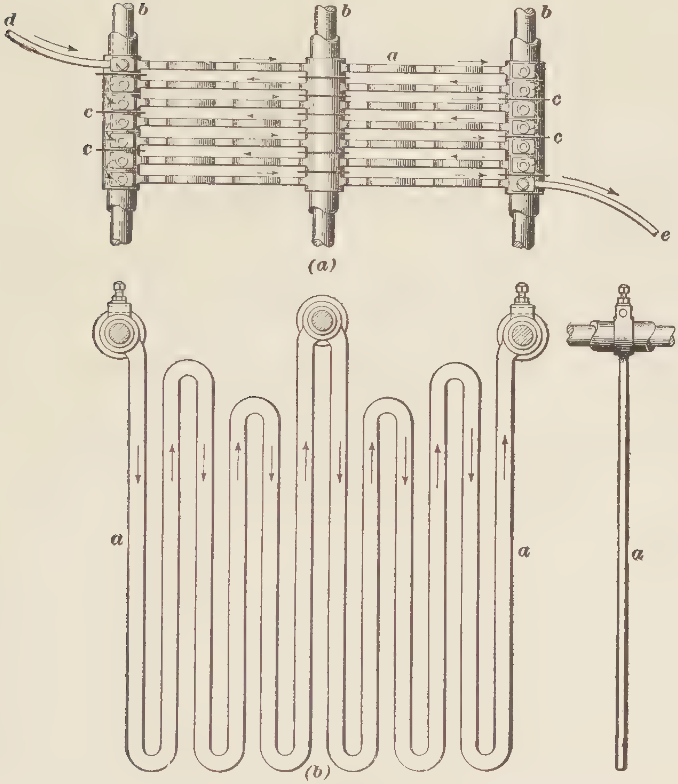


FIG. 23

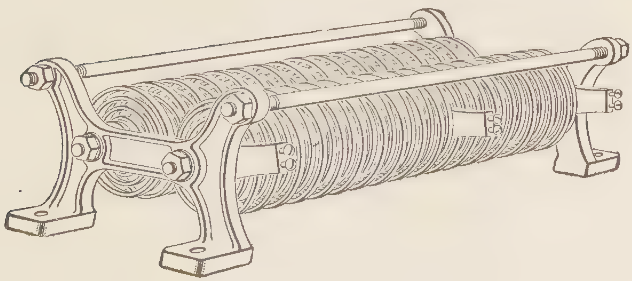


FIG. 24

an air space being left between the sections of the winding; (*a*) shows the coil and (*b*) one of the iron hangers used for suspending the coils from the car sill.

22. General Electric Grid Coil.—Fig. 22 is a view of the General Electric type of **grid coil,** of which Fig. 23 (*b*) shows the shape of the cast-iron grid and (*a*) the zigzag path of the current through the grids. The grids *a*, *a* are assembled on insulated studs *b*, *b*, end plates *c*, *c*, Fig. 22, being then put on and the whole compressed into a solid mass by drawing up on nuts *d* at both ends. Feet *f* are for hanging the coil from the car floor. On the middle stud *b*, Fig. 23 (*a*), all the grids are separated from each other by mica insulating washers. On the two outside studs *b*, however, considering any two adjacent grids, they touch each other on one stud, but on the other stud they are separated by a mica washer.

FIG. 25

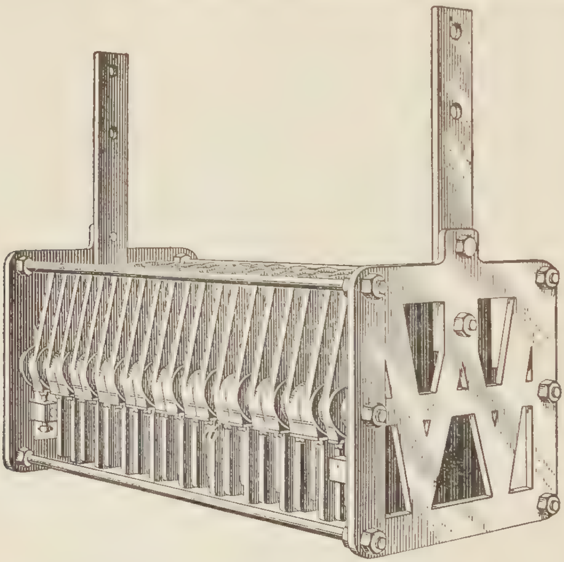


FIG. 26

The current entering at one end is thus compelled to take a zigzag path to the other end, as shown by the arrows. The

coil shown represents the unit starting coil used in heavy traction work, a complete starting coil of any desired capacity being composed of the required number of unit starting coils connected in series or parallel, or both. The coil used for surface trolley-car work is of the same construction, but is longer and may contain several sizes of iron.

23. Lundie Grid Coil.—Fig. 24 is a general view of the **Lundie grid coil**, and Fig. 25 shows the shape of grid used. The method of assembly is the same as that of the General Electric, except that contact between adjacent grids is improved by inserting a soft copper washer between them.

24. Westinghouse Grid Coil.—Fig. 26 is a general view of the grid coil. The general method of assembly is the same as that of the preceding examples, with the exception that adjacent grids are connected by means of a brass plate screwed to both of them, as shown at *a*.

CAR-WIRING REQUIREMENTS

25. Strictly speaking, the name **car wiring** includes all wires necessary to the operation of a car, but it is generally understood to apply only to the wires that interconnect the controllers, motors, resistances, and the ground; that is, the wires and dependent taps included in a consideration of the wiring cable of an ordinary car. The connections of the heaters and lamps are referred to independently as the heater wiring or the lamp wiring, while the stretch of circuit extending from the trolley stand to the controller trolley wire is referred to as the trunk wiring. On cars of moderate weight, it is customary to run the wires in a canvas hose or in conduit extending from one controller to the other, the hose being slit at intervals to let out taps that connect the several car wires to their respective controlling, operating, or safety devices. On heavy cars involving the use of large currents, the car wires are not bunched together in a hose, but are run separately on a smooth insulated surface, specially prepared for them, if necessary, and afterwards covered with specially molded insulation.

Fig. 27 illustrates a molded insulation, called *electrobestos*, used for this work. In ordering such expensive insulation, great care must be taken to get a correct plan of the proposed layout of the car wires, for mistakes in regard to it will be expensive. The car for which the samples of electrobestos shown were made had its under surface prepared within the working area by laying a sheathing of hard maple, this wood being comparatively free from acid; nailed

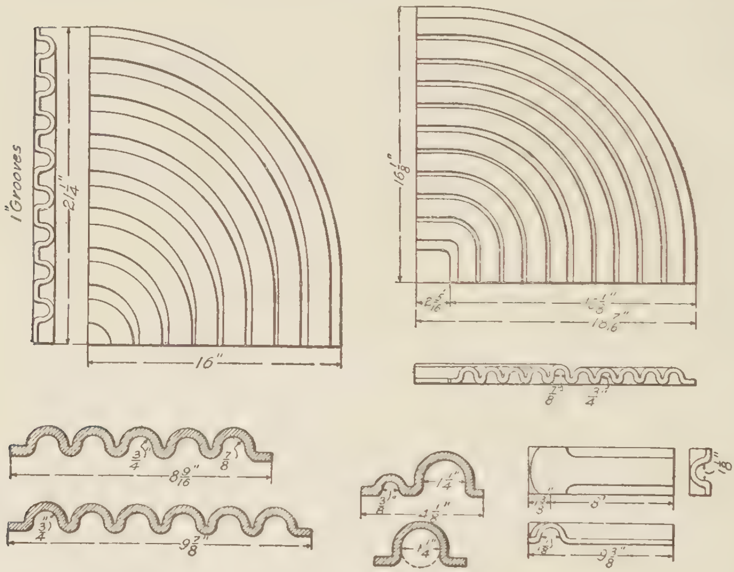


FIG. 27

to the maple sheathing was a ¼-inch layer of *transite board*, another special insulation not affected by water. After the installation of the transite, all nails passing through it were tested for insulation to see that they touched no grounded part. The molded type of insulation is specially adapted to those equipments on which all main-motor wires can be kept under the floor, the area to be insulated being there more congested and limited than on equipments employing platform controllers.

26. The following abstracts from the rules of the National Board of Fire Underwriters emphasize the importance of taking every practicable precaution to minimize the fire risk when installing car wiring, and thereby incidentally minimize the chances of operating troubles.

On cars equipped with motors of over 75 horsepower each, the under side of the car body should be lined with at least $\frac{1}{8}$-inch approved insulation material or sheet iron or steel $\frac{1}{25}$ inch in thickness, extending 8 inches beyond all edges of motor openings, resistances, and other electrical apparatus not amply protected by the containing case. All conductors must be stranded and joints must be so spliced as to be both mechanically and electrically secure without solder, then soldered and covered with insulation equal to that on the conductor. All cut-outs and switches having exposed live metal parts are to be located in asbestos-lined cabinets. Cut-outs and switches not in iron boxes or in cabinets must be mounted on not less than $\frac{1}{4}$-inch fire-resisting insulating material, which must project at least $\frac{1}{2}$ inch beyond all sides of the cut-out or switch. A cut-out switch must be placed as near as practicable to the current collector so that the opening of the fuse in this cut-out will cut off all current from the car. All conduits where exposed to dampness must be water-tight. All junction and outlet boxes must be so installed as to be accessible. Joints in molding must be mitered to fit close, the whole material being firmly secured in place by screws or nails and treated inside and out with waterproof paint.

27. The current used in determining the size of trolley, motor, and resistance leads is taken as a percentage of the full-load current, as given in Table I.

Table I is to be used in conjunction with Table II, taken from the Underwriters' table of carrying capacity of rubber-covered wires.

Suppose that it is required to determine the size of trunk wire to be used with an equipment of four 50-horsepower motors. The total horsepower is 200, corresponding to a

current (theoretically) of 300 amperes at 500 volts. From Table I, the size of wire is to be based on 40 per cent. of the current. $.40 \times 300 = 120$ amperes. From Table II, the allowable size for 120 amperes is No. 0 B. & S., having a cross-section of 105,500 circular mils.

TABLE I

Size of Each Motor Horsepower	Motor Leads Per Cent.	Trolley Leads Per Cent.	Resistance Leads Per Cent.
75 or less	50	40	15
Over 75	45	35	15

TABLE II

B. & S. Gauge	Amperes	Circular Mils
8	33	16,510
6	46	26,250
5	54	33,100
4	65	41,740
3	76	52,630
2	90	66,370
1	107	83,690
0	127	105,500
00	150	133,100
000	177	167,800
0000	210	211,600

The size of *motor leads*, by which is meant the size of wire running from each motor terminal, is obtained as follows: The full-load current of each motor is 75 amperes; from Table I, 50 per cent. of 75 amperes is $37\frac{1}{2}$ amperes; from Table II, the wire to be used is No. 6 B. & S.

ELECTRIC-CAR-HEATING APPLIANCES

ELECTRIC HEATERS AND CONNECTIONS

28. All **electric-car heaters** are made on the principle of forcing sufficient current through a resistance to heat it. A case keeps the feet and clothing of passengers from the hot wire. According to the size of car and the make of heater, four, six, eight, ten, twelve, or even twenty heaters are required per car. For a given amount of heat required, the smaller the heater and the more of them that are used, the more evenly will the heat be distributed through the car, but the more places will thus be created where trouble is liable to arise.

As regards efficiency, heaters of all makes are about the same. To keep a 20-foot closed car comfortable during average weather in the vicinity of New York requires a current of about 10 amperes at 500 volts; this is between 6 and 7 horsepower per car. Therefore, it costs considerable to heat a car by electricity, and when the heaters are in use there is quite a large additional load thrown on the station. On the other hand, electric heaters occupy no passenger space, they distribute the heat more uniformly than stoves, they are cleaner, and they allow the heat to be more easily regulated. For these reasons the electric heaters are extensively used, even though they are more expensive to operate than coal stoves. They are nearly always installed in such a manner that at least three degrees of heat can be obtained by operating a **heater switch,** which changes the connections of the heaters.

The number of makes and styles of heaters is large, and it would be out of the question to treat all of them here. One or two typical examples will be described, however, in order to illustrate the method of connecting, which is practically the same for all makes.

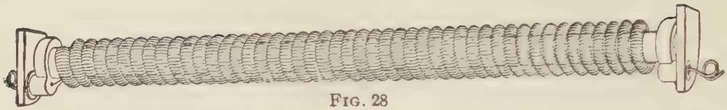


Fig. 28

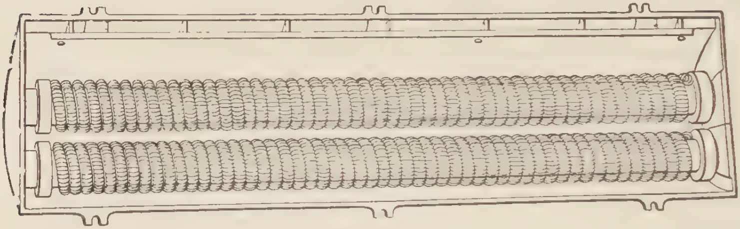


Fig. 29

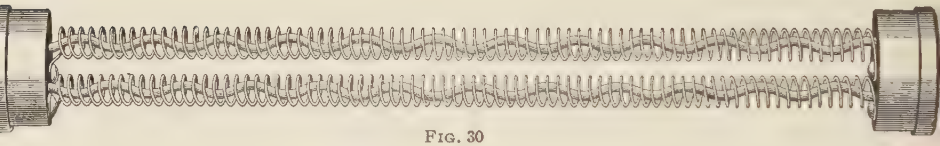


Fig. 30

Fig. 31

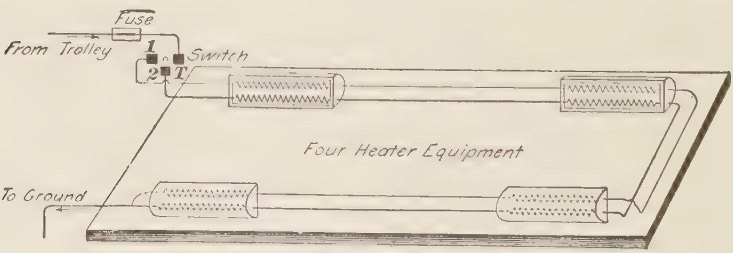


Fig. 32

TYPE OF PANEL HEATER

29. Fig. 28 shows the coil used in a standard type of car heater made by the Consolidated Car Heating Company and constructed as follows: On a stout rod are strung porcelain tubes that run the full length of the heater. These pieces have a spiral groove made continuous the full length of the core by the manner in which the porcelain-tube sections are placed on the rod. The heater coil is placed in this groove and a large amount of wire is thus placed in a limited space in a manner that admits of free circulation of air. The terminal wires that run out of the case at each end through porcelain bushings are attached to the ends of the coils by twisted and soldered joints and are well secured without the aid of binding posts. In each heater are two coils, like that shown in Fig. 28, placed one above the other, as indicated in Fig. 29, which represents a heater with the front plate removed to show the two coils in place. The type illustrated is for a side-seated car, and is intended to be set into a rectangular hole cut in the seat panel. Similar but shorter coils are adapted to cases of cylindrical form to be installed under cross-seats.

Fig. 30 shows the style of coil and the method of mounting it in the cylindrical type of heater made by the Gold Car Heating Company. Fig. 31 shows the Gold cylindrical heater complete.

HEATER-WIRING DIAGRAM

30. All electric-heater systems employ practically the same method of connecting the heaters and regulating the heat. Each heater has two independent coils, one of higher resistance than the other. Fig. 32 shows the heater wiring for a set of four Consolidated heaters controlled by the heater switch illustrated in Fig. 33. All top sections of the heaters are connected in series and all bottom sections are similarly connected. The negative ends of both sections of the last heater are grounded, on a ground-return system, or permanently connected to the negative conductor of a

metallic-return system. The positive ends of the two series of sections are so connected to the heater switch that on the first position of the handle all top sections are in series across the line; on the second position, the top sections

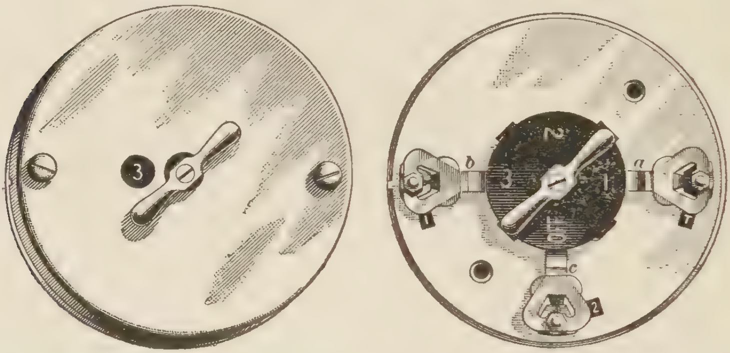


FIG. 33

are cut out but the bottom sections are in series; on the third position, the top and bottom sections are in parallel with each other, thus giving the greatest degree of heat obtainable with the given heaters. On the off-position of the heater switch all current is cut off.

OTHER SYSTEMS OF HEATING

31. Other devices than electric heaters are used for heating electric cars. Among them are the stove, hot-water system, and a system whereby the heat generated in the starting coil of the car is utilized. The main objection to electric heaters is the cost of the energy required by them, being more than one-third of that required to propel the car. The objections to **stoves** are the dirt that they make and the space occupied.

In the **hot-water system** of heating, the water flows through a closed circuit of heat piping including a pipe spiral contained in a firebox at one end or at the center of the car. The main objection to the hot-water system is the liability of

freezing unless the cars when not in use are kept fired or are laid up in a heated car house.

The **starting-coil heating system** is a feature of the combination traction brake and heat system of the Westinghouse Traction Brake Company. Resistance coils inside the car absorb the waste energy incident to starting and to generation of current by the motors when utilizing the traction brake. In warm weather such an arrangement would not be desirable, so that provision is made for then using the customary starting coil located under the car.

ELECTRIC-CAR LIGHTING

INCANDESCENT LIGHTING CIRCUITS

REMARKS

32. The **incandescent lighting circuits** on a car include the interior incandescent lamps, the rear platform lights of a surface trolley car, and possibly a hood or dash headlight, together with the facilities for changing over one or more lamps when the operating end of the car is changed. On cars to be made up into trains, there must be facilities for lighting both platforms on all but the forward car, which will probably also require signal lights, or markers, on the bonnet in addition to the headlight on the hood; and there must be change-over switches with which to change the headlight, markers, and platform lights to suit local conditions. In addition to lighting the car, the lamp circuit, when in good condition, is an indication as to whether the line is alive or not and as to the condition of the voltage.

EXAMPLES OF INCANDESCENT LIGHTING CIRCUITS

33. Fig. 34 shows a form of change-over switch that accomplishes the same result as the plug shown in Fig. 35. Both are used to cut one lamp out of circuit and cut another

in its place, as indicated in Fig. 36, which shows about the simplest arrangement of lamps for a car that must operate from both ends and always have a headlight and a rear-platform light. With the two plugs or switches in the full-line positions of the diagram, a headlight HL burns on both ends; with both plugs or switches in the dotted-line positions, a platform light PL burns on both ends. To get a headlight on one end and a platform light on the other, one switch or plug must be in the full-line position and the other in the dotted-line position.

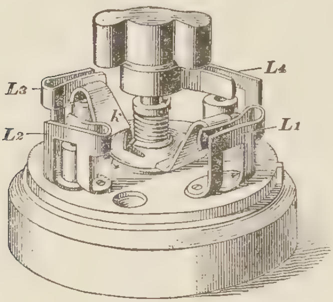


FIG. 34

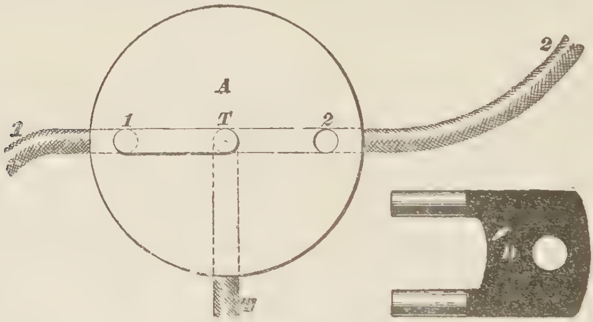


FIG. 35

34. Fig. 37 shows a plan of wiring for an elevated car employing both headlights and markers; the markers are

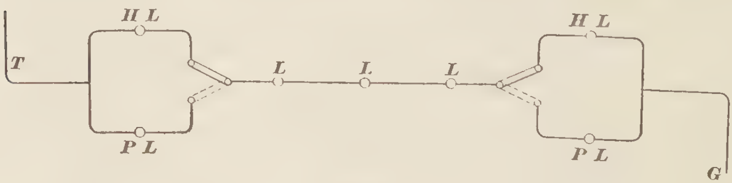


FIG. 36

intended to indicate the destination of a train. M, M and HL are the markers and headlight on one end of the

car and M', M' and $H'\ L'$ those on the other end. L, L, the two lamps inside the car, light whenever the signal lights on either end of the car are in use.

35. Fig. 38 is the lamp-circuit wiring for an interchangeable dash light wired in a five-lamp circuit; the headlight, of

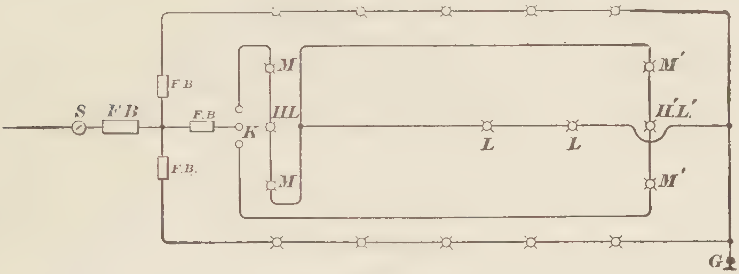


FIG. 37

course, has a lamp 7 of its own, and according as the headlight is on one end of the car or the other, lamps L_1 or L_5 are cut out and replaced by 7. In this figure, the headlight is in place on the right-hand end of the car and car lamp L_5

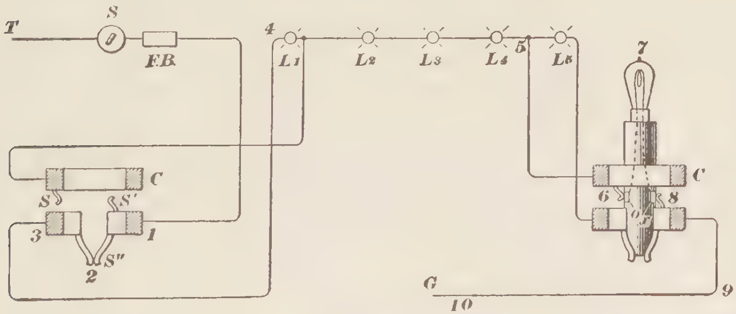


FIG. 38

is cut out. The path of the current is T–S–$F\,B$–1–2–3–4–L_1–L_2–L_3–L_4–5–6–7–8–9–10–G. In the side of the tongue that slides into the socket are two contact plates, shown at o and x, to which are connected the two wires from the posts of lamp 7. At S, S' are shown the springs that make contact with these two plates when the tongue is forced into the

socket. Springs S'' make a path for the current when the headlight on that end of the car is not in place. As soon as the tongue is dropped into the socket, its end forces the two springs apart and the current flows through the headlight.

ARC HEADLIGHT CIRCUIT

36. In suburban service, where cars run at high speed across numerous grade crossings, powerful **arc headlights** are used to illuminate the right of way for a considerable distance ahead of the car. In city work, the strong light projected by an arc lamp is undesirable.

Fig. 39 is a general, and Fig. 40 a sectional, view of the Crouse-Hinds combination arc headlight, which is provided

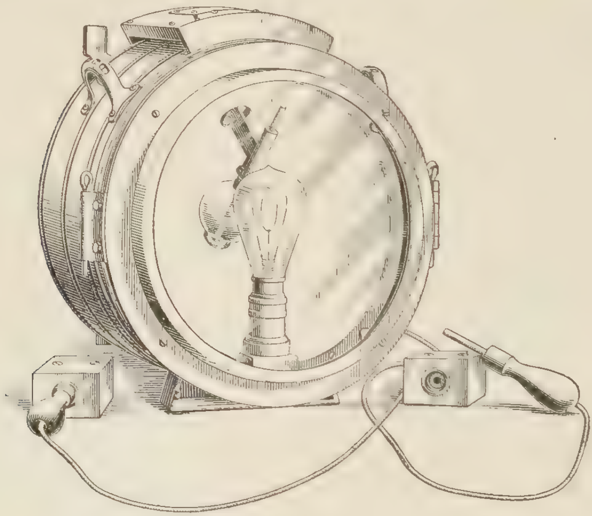


Fig. 39

with an incandescent light attached inside the door so that for city work the smaller light can be used. The arc-light carbons are inclined at an angle of 45° with the perpendicular, to present a large area of crater to the center of the reflector and to a certain extent overcome the dark spot usually present when vertical carbons are used. The initial drawing of the

arc or its reestablishment after running over a line breaker or otherwise interrupting the current, and the feeding of the carbon are automatically controlled by a coil in series with

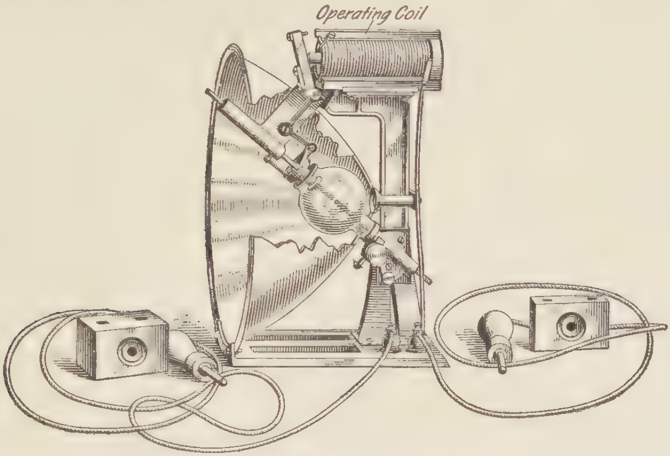


FIG. 40

the arc. The resistance used in series with the arc light is such as to admit a current of $3\frac{1}{2}$ amperes at 550 volts, the drop across the arc then being about 75 volts. Both the

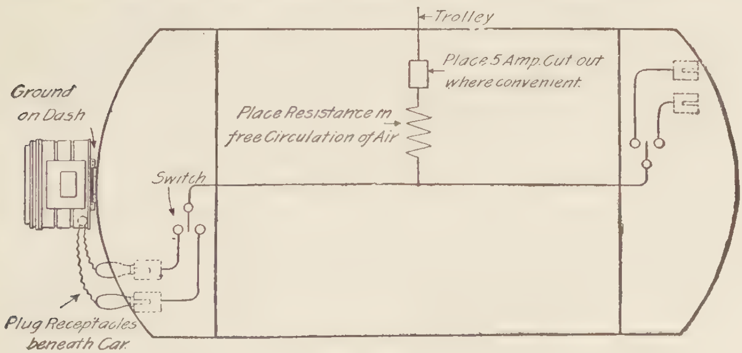


FIG. 41

incandescent attachment, supported on the door, and the arc-lamp circuits have plugs and receptacles of their own, and in order to obviate the necessity of pulling the plug of the lamp

circuit that it is not desired to use, both receptacles are connected to a two-way switch, the position of which determines which circuit shall be supplied with current. When the headlight is changed from one end of the car to the other

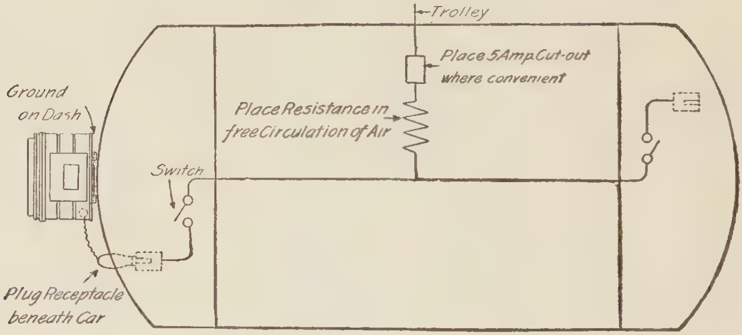


FIG. 42

both plugs must be removed from the receptacles. Fig. 41 is a diagram of connections when both lamps are installed, and Fig. 42, the connections for the arc lamp only, the incandescent attachment being omitted.

TRACK SIGNALS

37. On single-track electric roads, turnouts or sidings are provided to enable a fast car to pass a local and oppositely

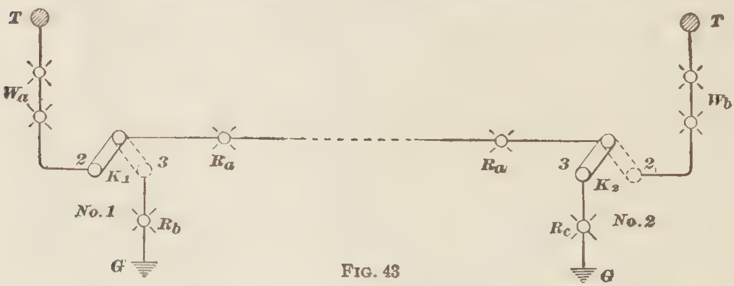


FIG. 43

bound cars to pass each other. The stretches of single track between sidings must be protected by signal systems, so that oppositely bound cars may not meet in collision or a

fast car run into a slow one. In some cases, elaborate automatic signals are installed, but usually the signal system is manual in operation, consisting of a signal-lamp box at each end of the stretch of single track connecting two turnouts. The signal generally takes the form of a red light to block a car, and a white light or no light to show a clear track. Fig. 43 illustrates the connections of a simple signal system.

38. Simple Signal System.—In Fig. 43, K_1 and K_2 are two-way switches, one of which is located at each end of the stretch of single track to be protected. The switch tongues are connected by No. 10 iron wire strung on the line poles and including two 16-candlepower incandescent lamps R_a, R_a provided with red globes. Each switch has a trolley contact *2* and a ground contact *3* including a red lamp (R_b and R_c). Each trolley contact includes two white lamps W_a, W_b. When the two switch tongues are in their full-line positions, white lamps W_a and red lamp R_a burn in the No. *1* signal box, while red lamps R_a and R_c burn in the No. *2* signal box. With the two switch tongues in their dotted-line positions, however, red lamps R_a and R_b burn in the No. *1* box and white lamps W_b and red lamp R_a in the No. *2* box. If both switch tongues rest on contacts of the same polarity, no lamps can burn.

39. Assume that a crew approaching the No. *1* box finds all lights out; under this condition either the system is out of order or both switch tongues are on ground or trolley. The conductor throws the handle to the opposite side, and if the lamps light it shows that they were extinguished by the conductor of another car leaving the block. If the lamps light just before he is able to throw the switch, it means that the conductor on a car entering the other end of the block has thrown his switch and the first car must wait until the second car comes through and clears the block. The conductor before entering the block now throws the switch to the other side to protect himself and throws the switch in the signal box at the other end of the block, when passing out, to clear the block for the next car.

BRAKES

INTRODUCTION

40. The most important part of any car equipment is the **brakes,** and they are closely involved in the financial success of a road. If cars are equipped with modern motive appliances but provided with a poor system of brakes, or if a good system of brakes is grossly neglected, loss due to accidents will be sure to result. Conditions governing the manner of applying brakes effectively vary widely, and the degree to which brakes in good order can be applied depends on the friction between wheel and rail and on that between wheel and shoe. When a brake is applied, the friction between wheel and rail tends to keep the wheel turning, while that between the shoe and wheel tends to stop the latter. The frictional effect tending to stop the wheel or keep it turning depends on the nature of the surfaces in contact and on the force with which the surfaces are pressed together.

The pressure tending to stop the wheel is proportional to the force exerted by the brake shoe; the pressure tending to keep the wheel rolling is proportional to the weight resting on the wheel. The permissible pressure to be applied to a shoe without locking a given wheel will vary with shoes of different material; for example, a shoe pressure that would not lock a wheel braked by an iron shoe might lock it if a wooden shoe were substituted, because the coefficient of friction of wood and iron surfaces is greater than that for iron and iron. In practice, where cast-iron shoes are used to brake cast-iron or cast-steel wheels, long experience has established the rule of making the shoe pressure applied to a wheel 90 per cent. of the weight resting on the rail under the wheel; and foundation brake riggings are designed accordingly. In electric-railway service, however, and

especially in high-speed service employing heavy motors, the pressure applied to the shoe is sometimes made 10 per cent. greater than the weight resting on the rail under the shoe. This increase in the percentage of braking pressure is rendered practicable by the inertia of the heavy rotating armatures, which tend to keep themselves and the geared wheels turning after braking pressure is applied, thereby making the effective weight tending to keep the wheel rolling greater than the actual weight resting on the rail. When all axles do not carry motors, care must be taken to design the foundation rigging so that the extra shoe pressure permitted by armature inertia will be applied only to those wheels that are geared to armatures.

Irrespective of the system of brakes used, the degree to which brakes can be effectively applied and the manner of applying them depend on the condition of the rail. An application that will stop a car satisfactorily on a clean rail may cause the wheels to lock and slide on a slippery one, the slippery condition seeming to affect the rail-wheel friction much more than it does the shoe friction. Braking conditions on a slippery rail are improved by applying sand to one rail, as is usually done, and the improvement is increased 100 per cent. by sanding both rails, as is seldom done, except in steam practice.

On surface trolley cars, hand-brakes are generally used; they can be designed to stop the heaviest cars at high speeds, but in doing so the travel of the brake-lever arms becomes so great that considerable time is required to take it up and effect a stop. On high-speed suburban cars, on elevated cars, and for other heavy traffic, air brakes are used. On single cars or on two-car trains, straight air brakes are used, while on longer trains automatic brakes are depended on. All forms of power-brake equipment, however, are supplemented by hand-brakes, which are retained as a factor of safety in case the power brake should fail or should it be necessary to brake a car cut off from the source of power.

HAND-BRAKES

SINGLE TRUCK

41. Fig. 44 shows a common form of **single-truck brake rigging,** most of the parts of which are designated in the figure. Brake beams B, B are supported on the ends and slide in cast-iron brake-beam castings fixed to the side frames of the truck. In Fig. 45, A is the slide casting; B, the beam; and F, the truck member that supports the casting. Equalizer rods r, r, Fig. 44, connect to equalizer bars E, E and each equalizer rod ends in a jaw J, to which the equalizer bars are rigidly connected, but in which the brake beams move freely, as shown in Fig. 46, where R is the rod; J, the brake jaw; B, the beam; and E, the equalizer bar. In Fig. 44, links H, H are connected to the brake levers L, L and equalizer bars by means of pins. Links I, I connect the brake lever and brake beams. F is a pin around which L and H can move, and F_1 is a pin common to L and B. In the diagram, the brakes are shown off and the shoes have been pulled away from the wheels by the release springs K, K. One end of each spring

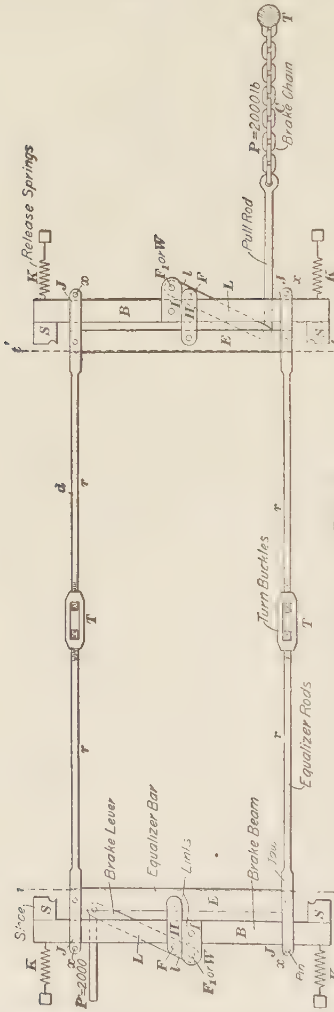


Fig. 44

is fixed to a lug on the car truck and the other end to the brake beam or shoe head. Brake slides wear rapidly and give trouble in winter by getting stopped up with frozen mud; the main objection is that the harder the brakes are set, the harder the brake beams press against the brake slide castings, with the result that the harder the brakes are set, the harder it is to set them. The operation of the brake will be apparent from an examination of Fig. 46. The force exerted on the pull rod P, Fig. 44, draws the brake beams B, B together, and thus presses the shoes S, S against the wheels.

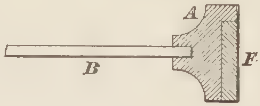


FIG. 45

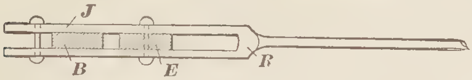


FIG. 46

42. The main objections to existing single-truck riggings are that the release springs do not always effectively keep the brake shoes off the wheels, and the nature of the lever construction is such that the brakes apply harder on the rear end than on the forward end. A glance at the brake rigging of almost any single truck will show that the shoes on one end are an inch or more away from their wheels, while those on the other end cling to their wheels. The brake levers are all released, but the release springs on one end being stronger than on the other pull the weaker springs out and force their shoes to the wheels with pressure depending on the difference in strength of the opposing release springs. Fig. 47 illustrates diagrammatically the leverage of one end of the single-truck rigging of Fig. 44. Lever PFW is 36 inches long and S_2 is the rear brake beam connected to PFW at F, through rod FS_2; S_1 is the front brake beam. Supposing the shoes on beam S_2 to be against their wheels,

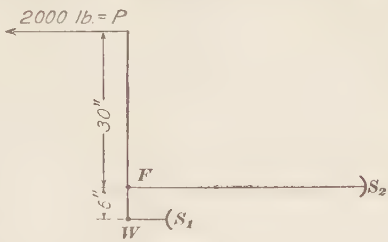


FIG. 47

a pull of 2,000 pounds at P, in the direction of the arrow,

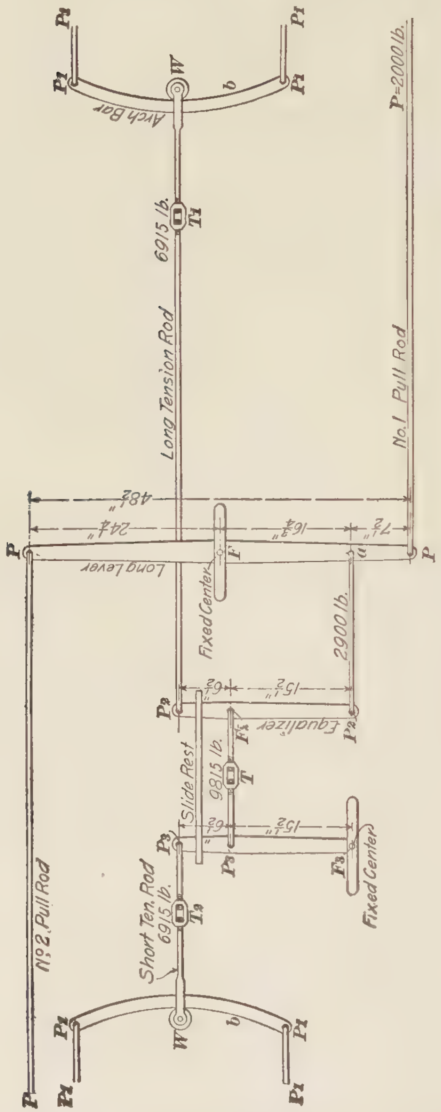


FIG. 48

will force beam S_1 against its wheels with a pressure of $\frac{30}{6} \times 2{,}000 = 10{,}000$ pounds. Supposing the shoes on beam S_1 to be against their wheels, a pull of 2,000 pounds at P will pull beam S_2 to its wheels with a force of $\frac{36}{6} \times 2{,}000 = 12{,}000$ pounds, a difference of 2,000 pounds, because beam S_1 is applied by a lever having its fulcrum between the applied force and the delivered force, whereas beam S_2 is operated by a lever having the delivered force between the fulcrum and the applied force.

DOUBLE-TRUCK BRAKES

43. Fig. 48 shows a type of **double-truck rigging** much used. The tendency to apply the rear brakes harder than the forward ones exists on double-truck riggings, and is overcome by the use of an extra equalizing

lever that cannot well be applied to single trucks. In Fig. 48, fulcrum F and fulcrum F_3 of the equalizing lever are fixed to the car body. Levers $P_2 F_2 P_2$ and $P_3 P_3 F_3$ are supported by a strap hanger that permits horizontal sliding motion and are connected by turnbuckle rod $F_2 P_3$. The rigging is indicated in the position of best leverage, the brake being set. Assume a pull of 2,000 pounds to be exerted on lower pull rod P causing the lower end of lever PFP (of which the long arm PF is $24\frac{1}{4}$ inches and the short arm, $16\frac{3}{4}$ inches) to move to the right and thereby exert a pull on rod $a\,P_2$. The pull on $a\,P_2$ is $\frac{24\frac{1}{4}}{16\frac{3}{4}} \times 2{,}000 = 2{,}900$ pounds. As rod $a\,P_2$ connects to lever $P_2 F_2 P_2$, 2,900 pounds is the pull applied to this lever, of which the long arm is $15\frac{1}{2}$ inches and the short arm $6\frac{1}{2}$ inches, the fulcrum being at F_2 and the power being applied to the long arm. Accordingly, the pull on tension rod $P_2 W$ is $\frac{15.5}{6.5} \times 2{,}900 = 6{,}915$ pounds. The pull on turnbuckle $F_2 P_3$ is $6{,}915 + 2{,}900 = 9{,}815$ pounds, which if applied directly to the short tension rod $P_3 W$ leading to the arch bar of the rear truck would apply excessive braking pressure. To avoid such a condition, equalizing lever $P_3 P_3 F_3$ is introduced, the effect of which is to make the pull on short tension rod $P_3 W$, 6,915 pounds, the same as on the long rod $P_2 W$, thereby insuring that the braking pressure on both trucks shall be the same.

44. Rods P_1, P_1 connecting to the ends of the arch bars are the truck pull rods that apply the braking pressure to the truck levers. Fig. 49 shows half the truck rigging on a truck equipped with inside hung brakes. A pull to the left on rod $P P_1$ forces shoes S_1, S_2 against their respective wheels, rod $P_2 P_3$ being subjected to compression.

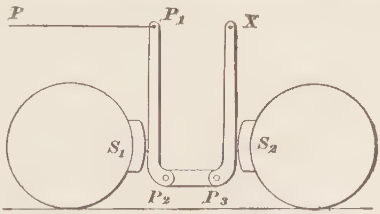


FIG. 49

MAXIMUM-TRACTION BRAKES

45. The body rigging for **maximum-traction trucks** is the same as that for ordinary double trucks, but the truck rigging must be modified to divert the greater part of the braking pressure to the large wheels, the axle of which supports more than two-thirds of the weight of the motor. Fig. 50 illustrates half of the truck rigging used on the Peckham maximum-traction truck. Bent lever *A* has the truck pull rod connected to its upper end, while its lower end attaches to a push rod that operates the shoe *S* of the large wheel. Lever *A* has no stationary fulcrum, but is pivoted at *y* to lever *B*, which has a stationary fulcrum at *x*. The lower end of lever *B* connects to a push rod that applies the brake shoe *s* to the small wheel. A pull to the left on the pull rod turns lever *A* in a counter-clockwise direction on *y* as a center, thereby applying the large shoe *S* to the wheel; *z* then becomes a center around which lever *A* continues to turn, thereby causing lever *B* to turn in a clockwise direction on fixed center *x*, the lower end of *B* forcing small shoe *s* against its wheel. The movements of the large and small shoes have necessarily been considered consecutively, but as a matter of fact they take place simultaneously.

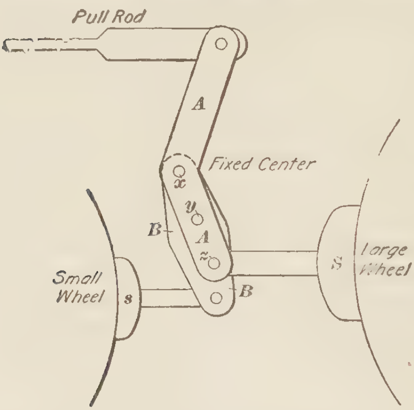


FIG. 50

STRAIGHT AIR BRAKES

46. General Remarks.—By a **straight air brake** is meant one operated by compressed air admitted from a storage reservoir directly to the brake cylinder without dependence on any automatic device. The straight air brake represents one method of securing a quick-acting powerful

brake, effective without manual exertion on the part of the operator, and free in design from excessive leverages. The air used for operating a straight air equipment may be compressed at stations located along the line and stored in a reservoir located on the car, in which case the system is known as the *storage air system;* or the compressed air may be obtained from an air compressor located on the car itself. In the latter case, the compressor may be driven from a car axle, in which case it is called an *axle-driven compressor*, or by an independent electric motor, in which case it is called an *independent-motor-driven compressor.*

47. Principal Parts of Straight Air Equipment. The principal parts of a straight air brake equipment that compresses its own air, are: the *air compressor*, usually driven by an electric motor; the *main reservoir*, or steel tank, into which the compressor stores the air to be used as required; the *automatic governor*, which starts and stops the compressor motor according as the main reservoir pressure is below or above a certain value; the *air gauge*, or *pressure gauge*, usually provided with a red hand, which indicates main-reservoir pressure, and a black hand, which indicates the pressure in the pipe line leading to the brake cylinder or cylinders; the *brake cylinder*, which carries a piston that operates the system of brake levers when communication is established between the reservoir and brake cylinder; the *engineer's valve*, by means of which the motorman lets air into the brake cylinder to apply the brake or discharges brake-cylinder air to atmosphere to release the brake; the *foundation rigging*, consisting of the various levers, rods, and carriers necessary to apply and support the brakes; the *pipe connections*, connecting the engineer's valves, brake cylinder, reservoir, compressor, governor, gauges, and coupling hose when the motor car is to haul a trailer or become part of a train.

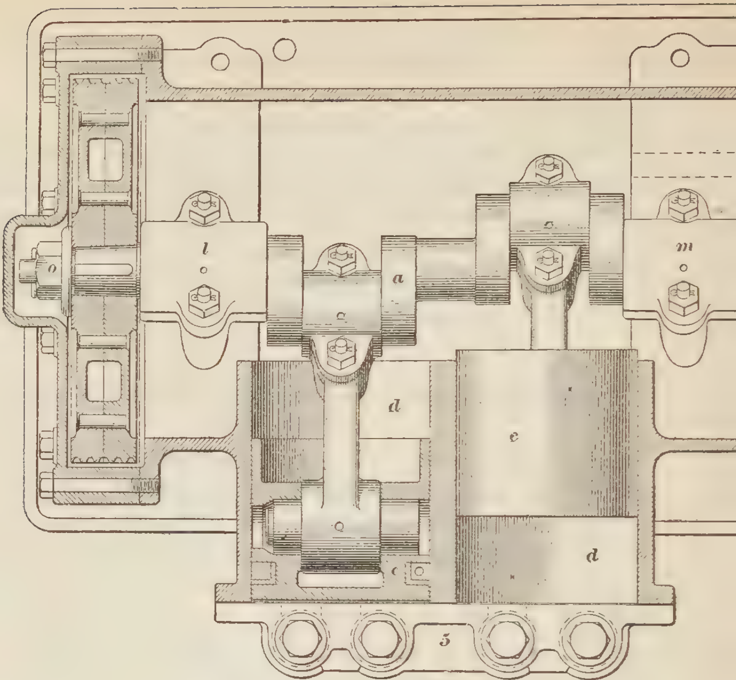
48. On a storage air car equipment, the compressor and all parts connected with it are replaced by reservoirs carrying air stored in them at high pressure at compressor stations

located at termini and at intermediate points, if necessary. A *service reservoir* carrying the air at the pressure at which it is admitted to the brake cylinder, is connected to the high-pressure storage reservoirs through a reducing valve. The equipment has the usual foundation rigging, brake cylinder, gauges, and engineer's valves, and the method of operation is the same as that of a compressor equipment.

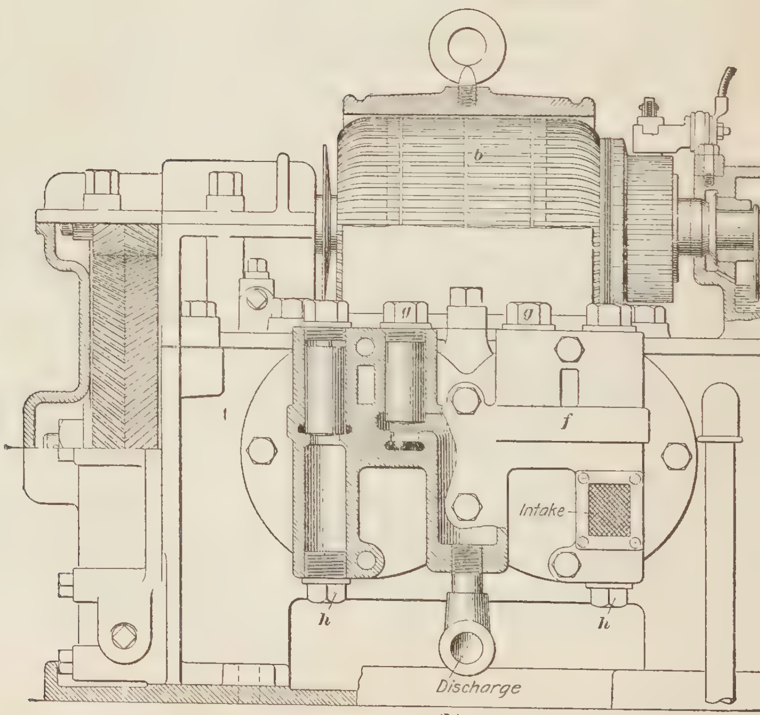
EQUIPMENT WITH INDEPENDENT-MOTOR-DRIVEN COMPRESSOR

49. The Compressor.—Fig. 51 is a perspective view of the Christensen compressor with the top half of the motor frame and the two bearing caps removed in order to take out an armature. Fig. 52 (*a*) is a horizontal section through the pump casing; Fig. 52 (*b*), a partial vertical section showing the valve construction; and Fig. 52 (*c*), a section at right angles to the crank-shaft. The rotation of crank-shaft *a*, geared at one end to the shaft of armature *b*, oscillates pistons *c* in cylinders *d*. The pistons connect at opposite ends of a crank-shaft diameter, thereby minimizing vibration. The two cylinders with valves at but one end, constitute a double-cylinder single-acting pump. The gear-case and the crank-shaft chamber are kept partially filled with oil poured in through elbow *e*, which also gauges the level of the oil. Cylinder head *f* contains all valves, and its removal exposes the ends of the pistons and cylinders. The air inlets are protected by strainers that exclude dust from the suction valves. All valves are interchangeable, excepting in so far as wear may affect them, and can be withdrawn by removing caps *g*. To clean the valve chambers, plugs *h* must be taken out. To remove an armature, disconnect and lift off the top field frame *k* and remove armature caps. To change a gear draw off the oil and remove nut *o* and the gear-case.

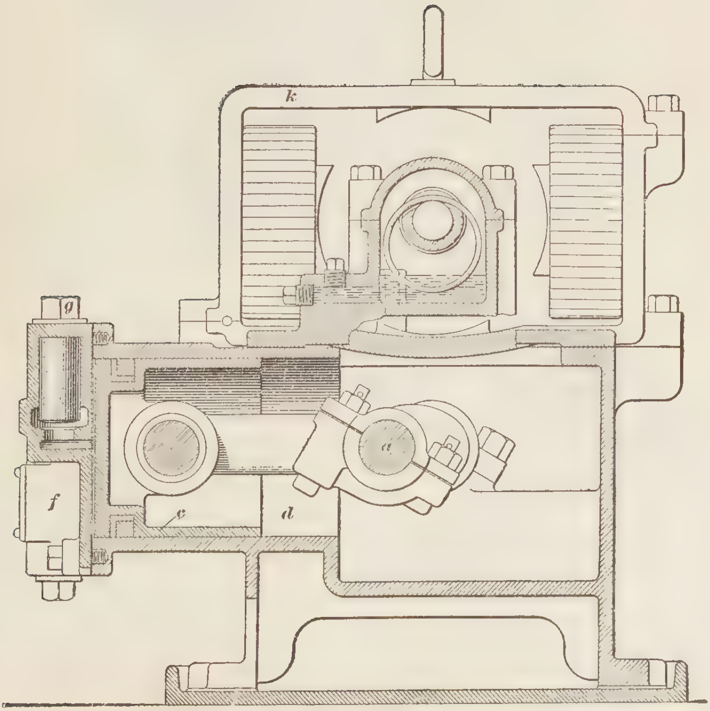
50. The compressor made by the General Electric Company is a departure from usual practice, in that it is driven through neither a worm nor a gear, the air pump pistons being directly connected to a slow-speed motor, also, the



(a)



(b)



(c)

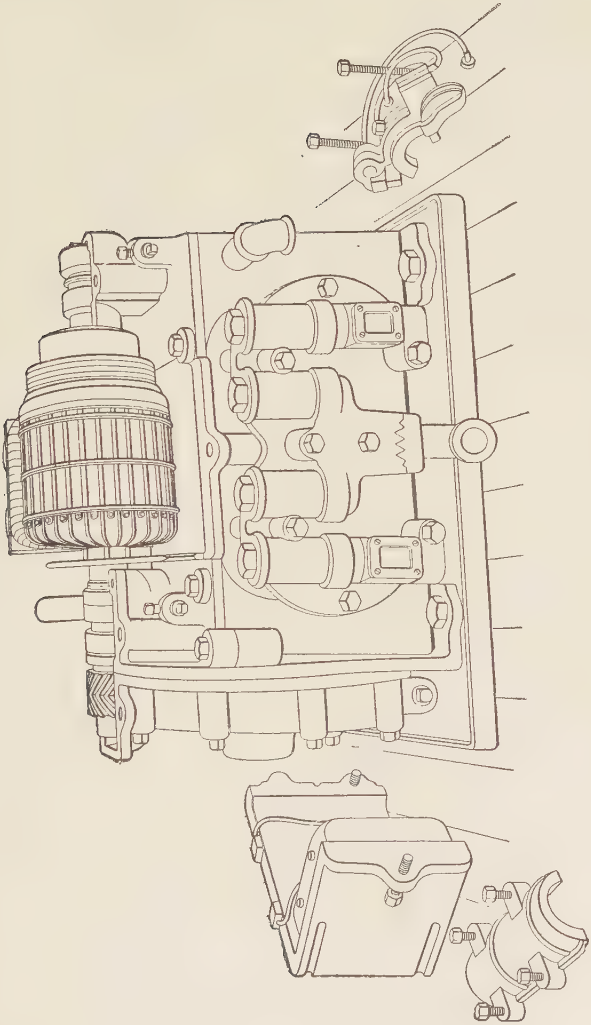


Fig. 51

pump action is compound instead of duplex. Fig. 53 is a sketch of connections showing a section through the governor *G*. Through fitting *a*, air from the reservoir enters chamber *b* behind rubber diaphragm *c*, which presses on plate *d*, the stem *e* of which actuates mechanism *f* and opens switch *g* when reservoir pressure exceeds a certain value; blow-out coil *h* suppresses arcing at the switch contacts. A second pipe (not shown) runs to the engineer's valve or reservoir line, as the case may be. Table III gives data relating to a number of different makes and sizes of air compressors used on electric cars.

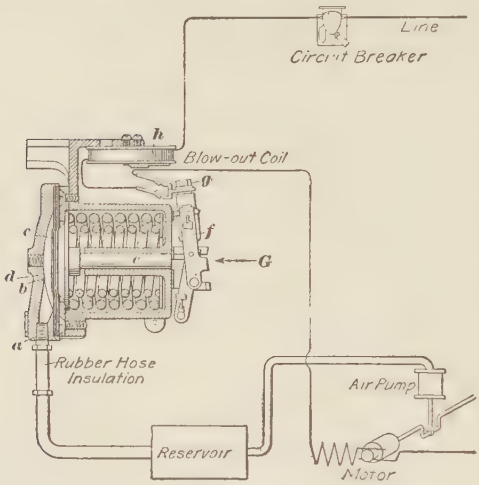


FIG. 53

51. The Engineer's Valve.—Fig. 54 is a vertical section through the Christensen engineer's valve, of which Fig. 55 shows the operating positions. The handle can be installed or removed only on *lap position*, so called because on this position all ports in the valve seat are lapped or closed. Movement of the handle to the right until shoulder *m* interferes with it (*service position*) establishes a small opening between the valve ports leading to the reservoir and brake cylinder, bringing the car to a gradual or *service stop*. If the handle is forced to the right as far as it can go (*emergency position*), a large opening is created through which reservoir air rushes to the brake cylinder, bringing the car to an *emergency stop*. On the first position to the left of lap, a small opening is created between the brake cylinder and atmosphere, allowing the brake to release gradually; this position

TABLE III

CAPACITY OF MOTOR-DRIVEN AIR COMPRESSORS

Name of Compressor	Cylinder Dimensions Inches	Revolutions per Minute	Free Air per Minute Cubic Feet	Horse-power at 90 Pounds	Size of Fuse Amperes	Diameter of Suction Pipe Inch	Diameter of Discharge Pipe Inch	Length Inches	Width Inches	Height Inches	Net Weight Pounds
General Electric C. P. 14	$5\frac{7}{16} \times 2\frac{1}{2}$	300	20	5.00				28	$22\frac{3}{4}$	$15\frac{1}{2}$	800
General Electric C. P. 17	$4\frac{3}{4} \times 2$	300	12	3.25				$27\frac{1}{2}$	$19\frac{7}{8}$	13	600
Christensen A-5	$4\frac{1}{2} \times 2$	200	7.5	1.50	5	$\frac{1}{2}$	$\frac{1}{2}$	$19\frac{3}{8}$	16	$14\frac{1}{4}$	265
Christensen AA-1 . . .	$5 \times 2\frac{1}{2}$	195	11	2.20	7	$\frac{3}{4}$	$\frac{3}{4}$	$21\frac{13}{16}$	$18\frac{11}{16}$	$16\frac{3}{4}$	406
Christensen B-2	$6\frac{1}{2} \times 3$	175	20	4.00	10	$\frac{3}{4}$	$\frac{3}{4}$	$28\frac{1}{16}$	$20\frac{3}{8}$	$20\frac{13}{16}$	725
Christensen C-3	$7\frac{1}{2} \times 4$	175	35	7.00	15	1	1	$32\frac{1}{4}$	$24\frac{3}{16}$	23	950
Christensen D-4	$8\frac{1}{2} \times 4$	180	50	9.50	20	1	1	$35\frac{9}{16}$	25	$24\frac{3}{8}$	1,118
Westinghouse D-1 B . .	$5 \times 2\frac{11}{64}$	265	13.1	3.18	5	1	$\frac{3}{4}$	26	$23\frac{1}{4}$	16	633
Westinghouse D-2 B . .	$5\frac{1}{2} \times 4\frac{1}{4}$	243	23.4	5.40	10	1	$\frac{3}{4}$	$30\frac{5}{8}$	$27\frac{1}{8}$	$19\frac{3}{4}$	918
Westinghouse D-3 B . .	7×5	162	36	9.20	15	1	$\frac{3}{4}$	$33\frac{3}{4}$	$28\frac{1}{2}$	$22\frac{1}{4}$	1,185

is used for gradual releasing and for running and is therefore called the *slow-release* and *running position.* If instead of moving the valve handle to this position after an application it is moved to the extreme left to *quick-release position*, the

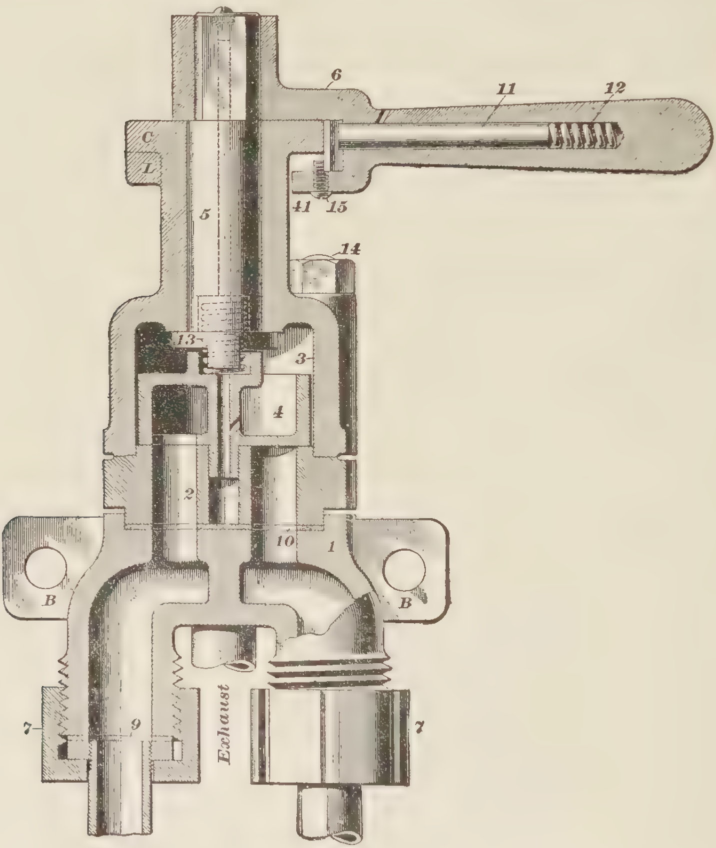


FIG. 54

size of the opening between the brake cylinder and atmospheric ports is such that the brake-cylinder air rushes out, allowing the release springs to release the brakes suddenly. On cars under headway, the valve is kept on slow-release, because the opening here existing between the brake cylinders

and atmosphere precludes the possibility of leakage across the face of the valve admitting air to the brake cylinder to set the brake unknown to the motorman. Quick-release is used for fully releasing the brake preparatory to starting after having made a stop. Slow-release is used for letting some of the air out of the brake cylinder when it is found

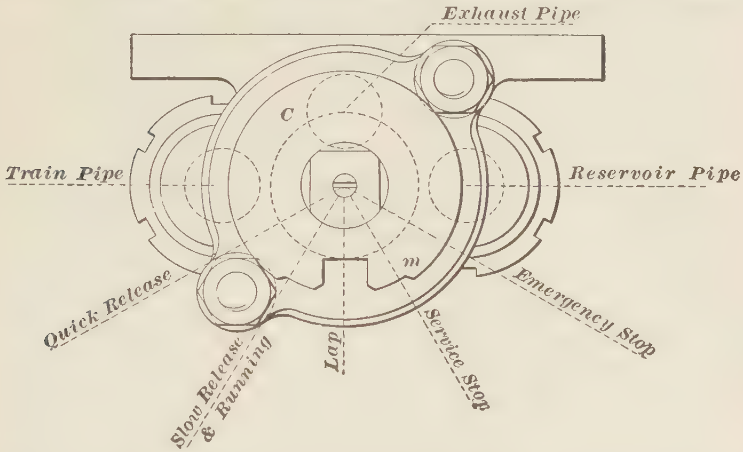


FIG. 55

that the car is going to stop too soon. The emergency position is used only in time of danger, and an emergency application should be accompanied by a liberal application of sand to the rail. An emergency application does not set the brake any harder than a prolonged service application, but sets it more quickly.

52. Each application of the brake reduces the pressure available for the next stop, but if the automatic governor is in order, the pressure cannot fall below a certain amount, for which the governor is adjusted. When the governor is out of order, however, it must be cut out and the starting and stopping of the compressor controlled by hand. Under this condition, the motorman must watch the pressure gauge and pull the switch when the gauge indicates maximum allowable reservoir pressure and close it when leakage or usage reduces the pressure to nearly the lower allowable limit.

The general practice is to allow a margin of 10 pounds, the maximum limit being 60 or 65 pounds and the minimum 50 or 55; there is, however, a tendency toward employing higher pressures—80 to 90 pounds. To reduce reservoir pressure from 60 to 50 pounds requires at least two emergency applications; the number of service applications required depends on the efficiency with which the applications are made and on the local track conditions. Less air is required to stop on an up grade than on a level; less on a level than on a down grade; and less on slippery rails than on good rails, to avoid locking the wheels.

53. Valves made by different companies vary somewhat in construction details, some, as in the case of the Christensen, being rotary valves, while others, like that of the Westinghouse Traction Brake Company, being slide valves; all operate to the same end. The off, or lap, position is always the neutral position in which the braking air is held in the condition existing at the time of lapping the valve, and only in this position can the handle be removed or installed—a precaution necessary to insure that the brakes may hold when the motorman removes the handle to change ends on a grade. Air at high pressure is hard to hold, and too much reliance must not be placed on lap position to hold air in the brake cylinder for a prolonged period. A car braked with air should not be left unattended unless the hand-brake has been set. If the handle is left on service position, all air must leak out of both the brake cylinder and reservoir before the brakes will release. If the governor and compressor are cut in and are in good condition, it cannot do this, but the pressure will be maintained at great loss of energy not to mention wear and tear on the compressor.

54. The Pressure Gauge.—A pressure gauge indicates the air pressure in the device to which it connects. Where two or more air-braked cars are to be operated together, a gauge having two hands, and called a *duplex gauge*, is used; one hand indicates main-reservoir pressure and the other the pressure in the *train line* or pipe connecting the brake

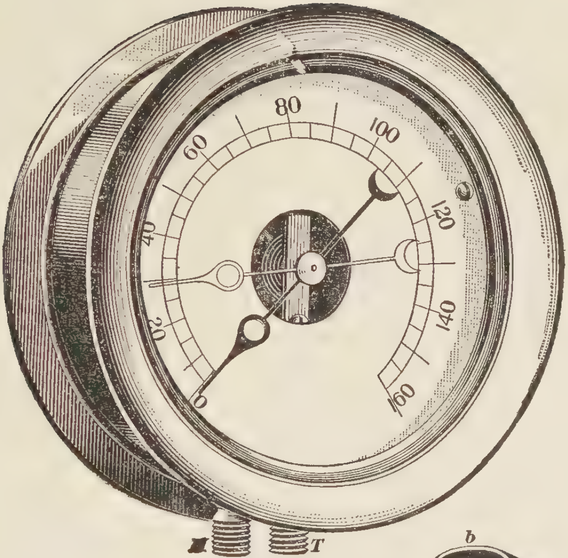
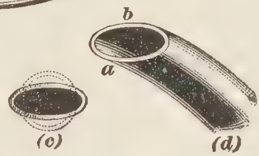


FIG. 56



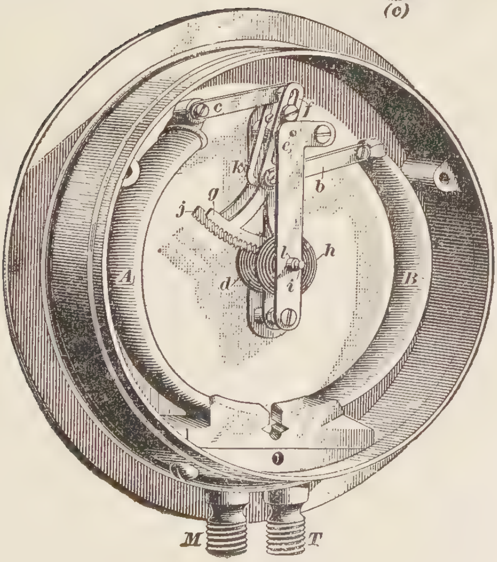


FIG. 57

cylinders together. Ordinarily, single-hand gauges are used on single cars, only main-reservoir pressure being indicated, but a duplex gauge represents the best practice in that it shows at a glance whether the brake cylinder contains air or not, and minimizes the probabilities of starting or running with the brake partially set.

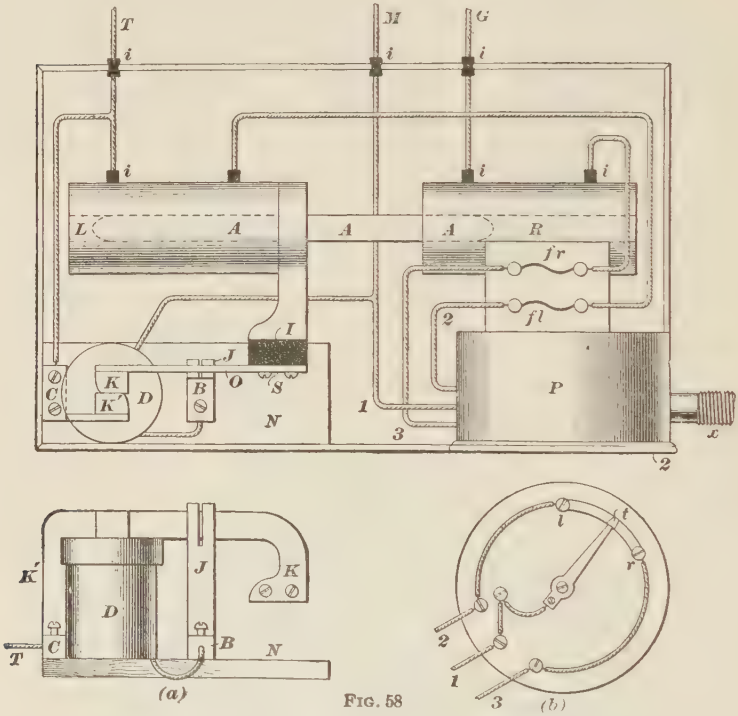


FIG. 58

55. Fig. 56 is a general view of a duplex air gauge, of which Fig. 57 shows the internal mechanism. The thin metal lobes *A*, *B* have the cross-section indicated in Fig. 57 (*d*), but internal pressure due to the compressed air tends to change them to the dotted cross-section of Fig. 57 (*c*), thereby giving the ends of the lobes lateral movement. Through racks *j*, *g* pivoted at *e*, the end motions of lobes *A*, *B*, respectively, are transmitted to pinions *d*, *h* on spindles *i*, *l* concentric with the pinions. These spindles carry the gauge hands, and since

lobe A fastens to the rack above the fulcrum and lobe B below the fulcrum, both hands move around the dial in the same direction. Connection M to the main reservoir admits air to the lobe that operates the red hand, while connection T to the train line admits train-line air to operate the black hand.

56. Automatic Governor.—Fig. 58 is a top view of the Christensen automatic governor, generally called the pump governor. L and R are electromagnets in which an iron armature A carrying an extension I is free to slide. K and K' are contact fingers, K' being stationary and K being carried by, but insulated from, extension I. D is a magnetic blow-out coil through which the current passes and which suppresses arcing when fingers K, K' are pulled apart. P is the regulator constructed on the same principle as a single-hand air gauge; the hand, however, instead of indicating pressure carries on its end a carbon knob t, which, according to the condition of main-reservoir pressure, touches contacts l or r. Connection x leads to the main reservoir. Fuses f_r, f_l protect the governor magnets. Connections T, M, and G passing through insulating bushings i connect, respectively, to trolley, the pump motor, and the ground. The connection to the regulator hand is made very flexible to avoid interfering with the movement of the hand.

57. Fig. 59 is a sketch of the connections of the governor of which the operation is as follows: The regulator hand t is so adjusted that at minimum allowable main-reservoir pressure, or less, it rests against contact post l leading to magnet L. Suppose that the reservoir is empty and that it is necessary to get up pressure: On closing the pump switch K, current comes in at T to junction X; if magnet L had been the last one to operate, armature A A would be at the left end of its travel and fingers K, K', Fig. 58, would touch, so that current could take path X–C–B–D–Y–M–M'–W–G, Fig. 59, through the pump motor and start it; the current through magnet L is negligible because it is practically short-circuited by the path just traced. In this particular case, then, when armature A A, Fig. 58, is already in the proper position

coil L does nothing. Suppose, however, that at the time of closing the pump switch, armature $A A$ happens to be to the right so that fingers K, K' cannot touch; in this case no current can get across the open circuit between C–B, and the pump motor cannot start at once; but current takes path X–L–f_l–l–t–Y–M–M'–W–G, Fig. 59, thereby exciting magnet L, causing it to jerk all parts to the left, thereby closing the motor circuit and simultaneously short-circuiting the magnet circuit, as already explained. As the gradually increasing pressure in the main reservoir and hence in the regulator lobe straightens out the lobe, knob t moves from contact post l toward contact post r. The instant it touches

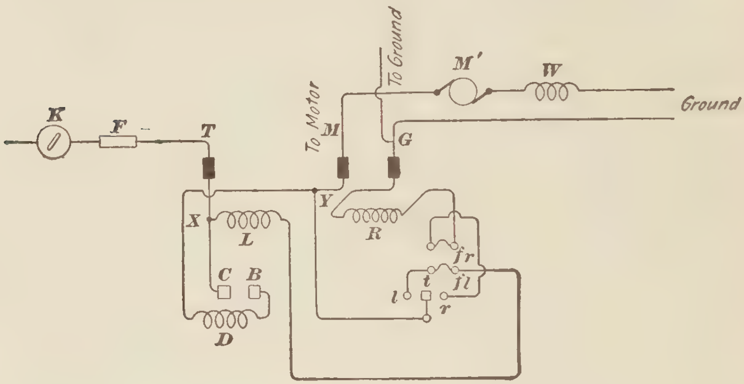


FIG. 59

post r, trolley current takes path T–X–C–B–D–Y–t–r–f_r–R–G, thereby exciting magnet R, which pulls armature $A A$, Fig. 58, to the right, opening the motor circuit and simultaneously stopping all current flow through itself. Armature $A A$ will remain at the right-hand end of its travel until usage or leakage reduces main-reservoir pressure to its lower allowable limit, when contact between regulator knob t and contact post l will again cut in the compressor.

Connecting posts r and l can be slid back and forth in the circular slot indicated in Fig. 58. By adjusting these posts in the slot, the governor can be made to cut in the compressor at one pressure and out at another.

58. The Brake Cylinder.—Fig. 60 is a section through a standard brake cylinder made by the National Electric Company (Christensen Engineering Company). In Fig. 60, *1* is the cylinder body; *2*, the front head; *3*, the back head; *4*, the piston; *6*, *7*, the front and back forks through which pass bolts *15* and *16*, around which turn the cylinder levers of the foundation brake rigging; *8* is the release spring; *11*, the piston packing bolts; *12*, the head-bolts; *13*, the hollow piston stem; *P*, the push rod. At *11* is a threaded hole for the piping to the engineer's valve.

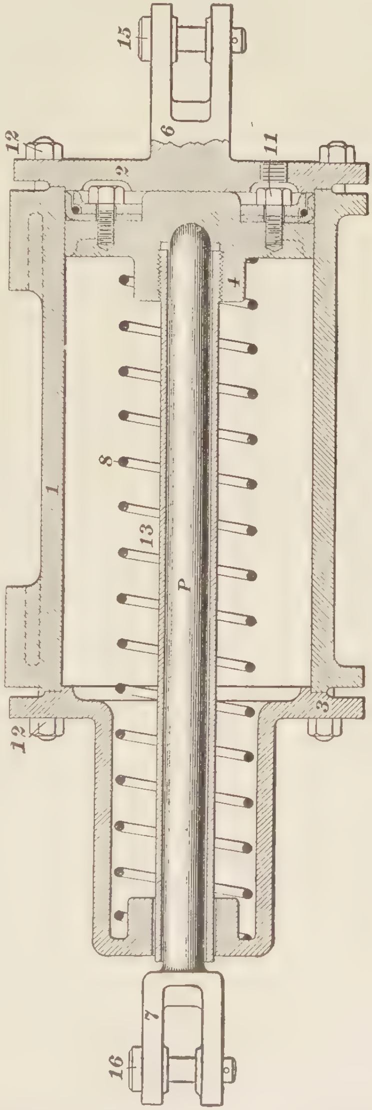


Fig. 60

The operation of the cylinder parts is as follows: Fork *6* is stationary; fork *7* moves back and forth with rod *P*, which operates the cylinder levers. Air admitted through hole *11* forces piston *4* to the left, carrying with it rod *P*, which moves the lever connected to pin *16* and sets the brakes. In moving to the left piston, *4* compresses spring *8*, so that when the brake valve is moved to release position exhausting brake-cylinder air to atmosphere, spring *8* returns piston *4* and

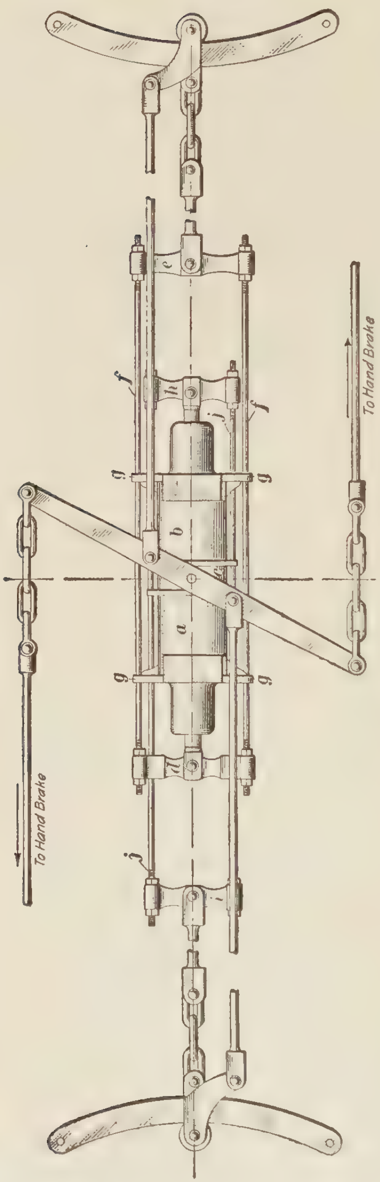


Fig. 61

hollow stem *13* to normal position. Since fork 7 and push rod *P* are independent of stem *13*, the push rod must be returned to normal position by the release springs on the brake rigging. The object of having *P* and *13* independent of each other is that when the hand-brake is used and push rod *P* must be pulled out, it will not be necessary to pull out *4* and *13* against the tension of spring *8*. The brake-piston travel should be kept within the limit prescribed by the manufacturing company, because beyond this limit the side pressure of the push rod *P* will be sufficient to split out the end of the hollow stem *13*.

59. Fig. 61 shows a brake cylinder manufactured by the Philadelphia Air Brake Company. As it really consists of two brake cylinders, each with its own piston rigging, it is called a **duplex** cylinder. In Fig. 61, *a* and *b* are the two cylinders accurately alined and bolted together at *c*, by flange bolts (not shown). Crosshead *d*, operated by

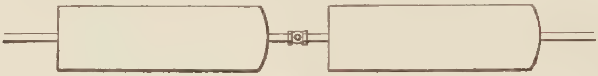
the piston of cylinder *a*, is connected to crosshead *e* by rods *f* that pass through guides *g*; and crosshead *h* operated by the piston of cylinder *b*, is connected to crosshead *i* by rods *j*, which also pass through guides *g*. Crosshead *e* is connected, by means of rods, to the arch bar that distributes the pull applied to the truck on one end and crosshead *i* is connected to the arch bar on the other end. When the air pressure is admitted to the cylinder space between the two pistons, they move apart, the one in cylinder *a* applying the brakes on the right-hand end and the piston in *b* applying them on the left-hand end. The breaking of a rod or lever connected with the rigging of one piston does not interfere with the braking power of the other, because the two riggings are entirely independent. The duplex air riggings, together with the independent hand-brake rigging shown, constitute three independent means of braking in an emergency. The duplex arrangement of cylinders simplifies the foundation rigging and equalizes the brake pulls applied to the two trucks without the use of special levers for that purpose.

60. The Reservoir.—The reservoir, Fig. 62, is a steel tank generally supported under the car by iron hangers bolted to the sills, but sometimes placed inside the car under the seats or even on the car roof. In cases where space is limited, two smaller reservoirs can be used instead of one

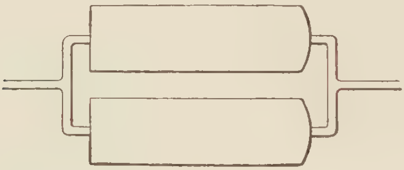
FIG. 62

large one. In such a case the two reservoirs should be piped in series, as indicated in Fig. 63 (*a*), and not in parallel, as in Fig. 63 (*b*). The first connection has the advantage that most condensation takes place in the first reservoir, leaving comparatively dry air to be used from the second one. The greater the capacity of the main reservoir, the higher is the

pressure with which it will equalize with a brake cylinder of given capacity in an emergency application and, hence, the quicker will be the stop. Also, the larger the reservoir, the longer will be the periods of rest and consequent cooling afforded the compressor motor, because once charged to maximum pressure, the greater are the number of applications that can be made without reducing the pressure sufficiently to cut in the compressor. For these two reasons, then, the main reservoir should be as large as practicable. In practice, main reservoirs and brake cylinders are limited to standard sizes adopted by the manufacturers.



(a)

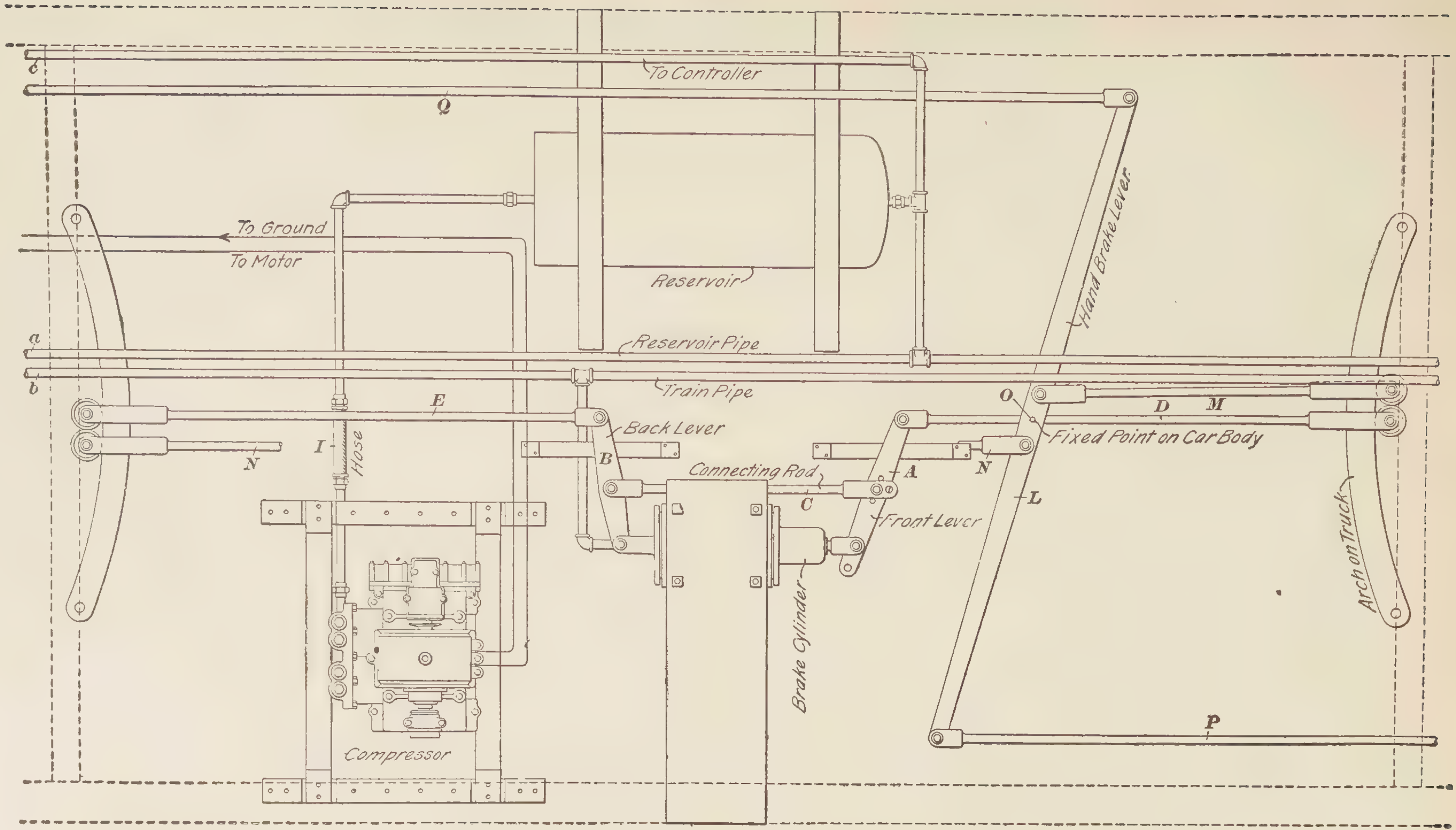


(b)

FIG. 63

61. Layout of Devices.—Figs. 64 and 65 show a layout of the Christensen straight air-brake equipment and give an idea of the location and interconnection of devices. If the two drawings are conceived to be held together so that points *a*, *b* on one register with the same points on the other, the result is a complete equipment for a single-end car; and if an extension similar to Fig. 65 be added also to the right-hand end of Fig. 64, the complete layout for a double-end car is the result. In these figures are indicated devices not heretofore considered—pipe and lever connections, coupling and insulation hose, hand-brake, and whistle.

62. The **air-brake lever system** is shown in Fig. 64, and consists of front and back cylinder levers *A*, *B* connected by rod *C*. Front and back brake rods *D*, *E* connect at one end to their respective cylinder levers *A*, *B* and at the other



To Controller
Q
c
To Ground
To Motor
Reservoir
a
Reservoir Pipe
b
Train Pipe
Hand Brake Lever
O
D
M
E
Back Lever
Fixed Point on Car Body
I
Hose
N
B
Connecting Rod
A
N
C
L
Front Lever
Arch on Truck
Brake Cylinder
Compressor
P

FIG. 64

end to the truck arch bars to which connect the pull rods from the individual truck brake riggings (not shown).

63. The **hand-brake lever system** is independent of that of the air brake, but in all cases its stresses are in the same direction. Hand-brake lever L is attached to the car body at O; pull rods P and Q fasten to the hand-brake staff through the brake chains. Winding up either chain, by turning the hand-brake wheel, causes lever L to turn around O, thereby pulling on brake rods M and N, which connect to the arch bars independently of air-brake rods D, E.

64. The **piping system** consists of a reservoir pipe a and train pipe b extending the full length of the car in the case of double-end control, but extending only from the engineer's valve to the brake cylinder and main reservoir in single-end control. The compressor is piped to the reservoir, the other end of which is joined to the reservoir pipe and pump governor (see pipe c, Figs. 64 and 65).

65. The **insulation hose** I, I are used to insulate the governor and compressor from the grounded devices to which they connect. When the frame of a device operating on a ground-return system is not grounded, the tendency of any current-carrying part to ground to the frame is greatly reduced. Two connections with the frame will be necessary to interfere with the operation of the affected device. In many cases an insulating coupling is used instead of the piece of hose.

66. Operation of Equipment.—Before taking a car out, the governor cock must be turned on and the pump switch closed. The governor will then cut in and start the compressor, which will store air in the reservoir until its pressure reaches standard value. On running a car into the house for the night, the pump switch should be opened, otherwise, if the pipe system has leaks, they will keep the governor cutting in and out and the compressor in intermittent operation all night.

In Fig. 65 only one snap switch is shown in the pump circuit; on double-end cars, two pump switches, one on each

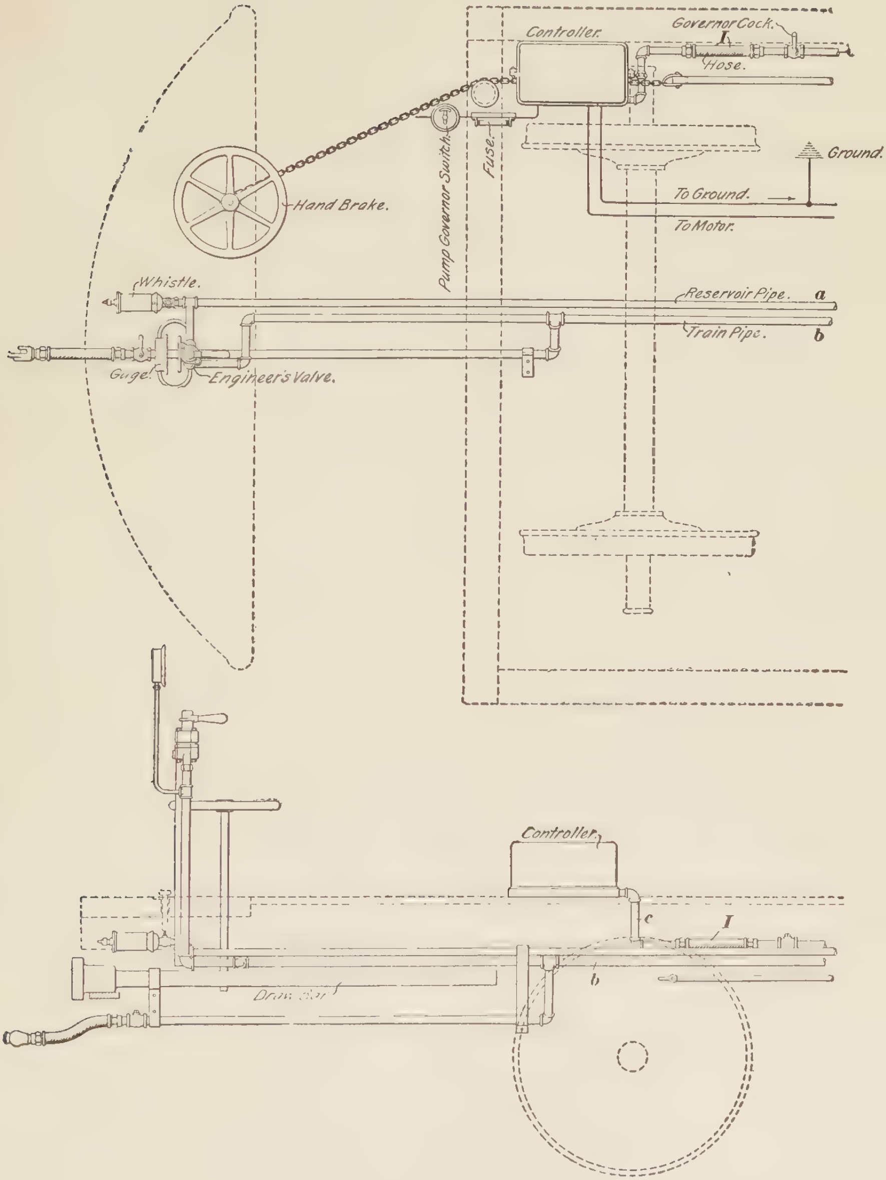

Controller.
Governor Cock.
I
Hose.
Ground.
Pump Governor Switch.
Fuse.
Hand Brake.
To Ground.
To Motor.
Whistle.
Reservoir Pipe.
a
Train Pipe.
b
Gage.
Engineer's Valve.
Controller.
c
I
b

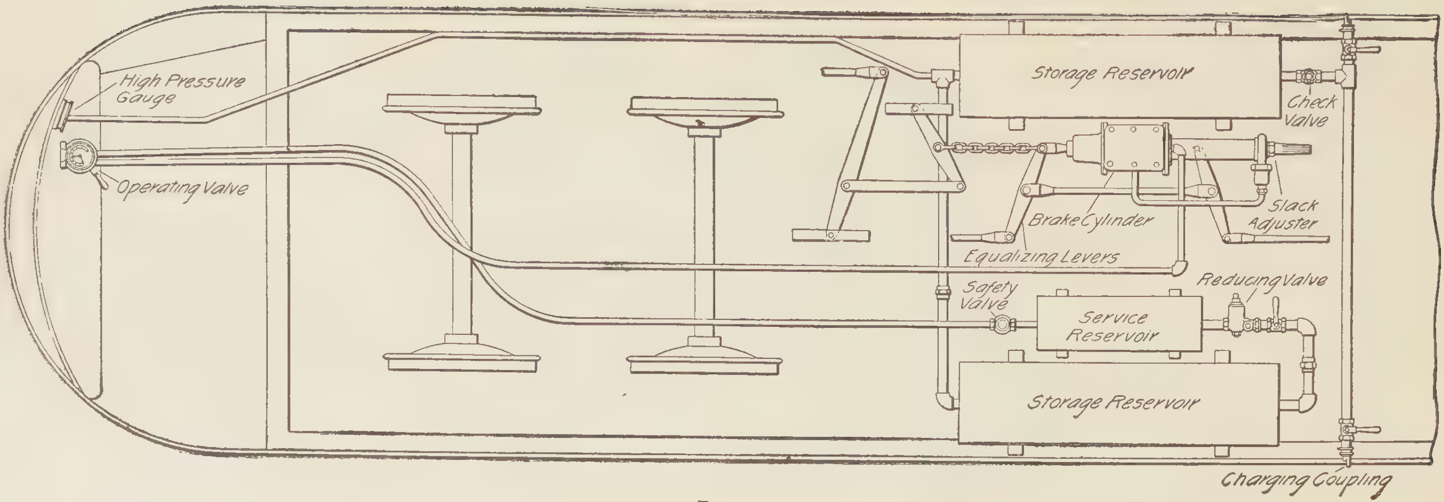
FIG. 65

end of the car and within easy reach of the motorman, are preferable, so that should the governor get out of order the motorman can conveniently control the air pressure by opening and closing the pump switch irrespective of the end on which he may be operating.

STORAGE AIR-BRAKE EQUIPMENT

67. General Remarks.—The engineer's valve, brake cylinder, reservoir, and lever system, and most of the piping used on an independent-motor straight air-brake equipment, can also be used on a storage air equipment. In addition to these parts, there must be storage reservoirs, a reducing valve between the storage and service reservoirs, various stop-cocks and check-valves, a charging coupling, and high-pressure gauge.

68. Fig. 66 is a diagram of the storage air-brake equipment installed on a double-truck car by the Westinghouse Traction Brake Company. Only one engineer's valve is shown connected, but two are installed where a car is to be operated from both ends. The charging couplings on both sides of the car are connected by a pipe that connects to one end of the high-pressure storage reservoirs. Charging air, at 325 pounds per square inch, on entering either coupling passes through one storage reservoir and then through a cross-pipe to the second storage reservoir. The air passes into the service reservoir through a cut-off cock and an automatic reducing valve, which keeps the service-reservoir pressure constant. The service reservoir connects to the engineer's valve, or valves, and includes a safety valve to insure against abnormal pressure getting into the brake cylinder should the reducing valve get out of adjustment. The gauge that indicates service-reservoir pressure is located in the head of the engineer's valve, a feature peculiar to the valve made by the Westinghouse Traction Brake Company. The gauge that indicates the pressure existing in the high-pressure reservoirs is a separate instrument that connects directly to one of them.



High Pressure Gauge
Operating Valve
Storage Reservoir
Check Valve
Slack Adjuster
Brake Cylinder
Equalizing Levers
Reducing Valve
Safety Valve
Service Reservoir
Storage Reservoir
Charging Coupling

FIG. 66

69. The Reducing Valve. — The reducing valve employed for maintaining constant pressure in the service reservoir is the well-known Westinghouse **slide-valve feed-valve** used for maintaining constant train-line pressure on automatic air-brake equipments. In the storage air equipment, the valve body is adapted for pipe connections from the storage and service reservoirs instead of a fitted

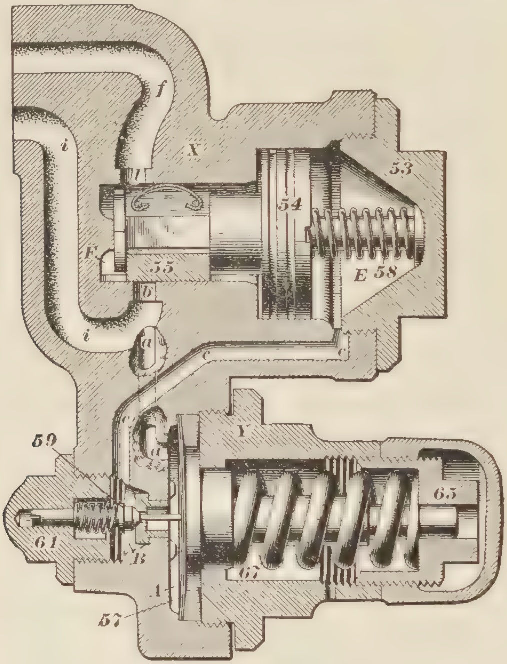


FIG. 67

connection to an engineer's valve. Fig. 67 is a conventional diagram in which the upper and lower valve parts, which are in planes at right angles to each other, have been revolved into the same plane in order to show the ports and passages more clearly. When used as a reducing valve, as on the storage air equipment, the high-pressure reservoir connects to a pipe fitting leading to port *f* and the service reservoir to a pipe leading to port *i*.

The operation of the valve is as follows: Storage-reservoir pressure is in continuous communication with chamber *F* through port *f*; chamber *E*, separated from chamber *F* by supply-valve piston *54*, is connected to passage *i* and thus with the service reservoir through passage *c c*, port *a* (controlled by regulating valve *59*), and chamber *A* over metal diaphragm *57*. Regulating valve *59* is normally held open by diaphragm *57* and regulating spring *67*, the tension of which is adjusted by regulating nut *65*. When open, chamber *E* is in communication with the service reservoir and is subject to service-reservoir pressure. Assuming that usage or leakage has reduced service-reservoir pressure below normal, storage-reservoir pressure in chamber *F* forces supply-valve piston *54* to the right, compressing spring *58*, carrying supply valve *55* with it and uncovering port *b*, through which air passes directly into the service reservoir through passage *i*, *i*, raising the pressure of the service reservoir. This increase of pressure in the service reservoir, hence in diaphragm chamber *A*, continues until it becomes sufficient to overcome the tension of regulating spring *67*, which was adjusted to give at standard service-reservoir pressure. Diaphragm *57* then yields, allowing regulating valve *59* to be seated by spring *60*, thereby closing port *a* and cutting off communication between chamber *E* and the service reservoir. The pressures in chambers *E* and *F* then equalize by leakage past supply-valve piston *54*, and supply-valve piston spring *58*, previously compressed by the relatively high pressure in chamber *F*, now reacts and forces supply valve *55* to its normal position, closing port *b* and cutting off communication between the storage reservoir and service reservoir. A subsequent reduction in service-reservoir pressure reduces the pressure in chamber *A* and permits regulating spring *67* to force regulating valve *59* from its seat, thereby causing the accumulated pressure in chamber *E* to discharge into the service reservoir. The equilibrium of pressure on opposite faces of supply-valve piston *54* being thus destroyed, the higher storage-reservoir pressure in chamber *F* again forces it, with supply-valve *55*, forwards and recharges the

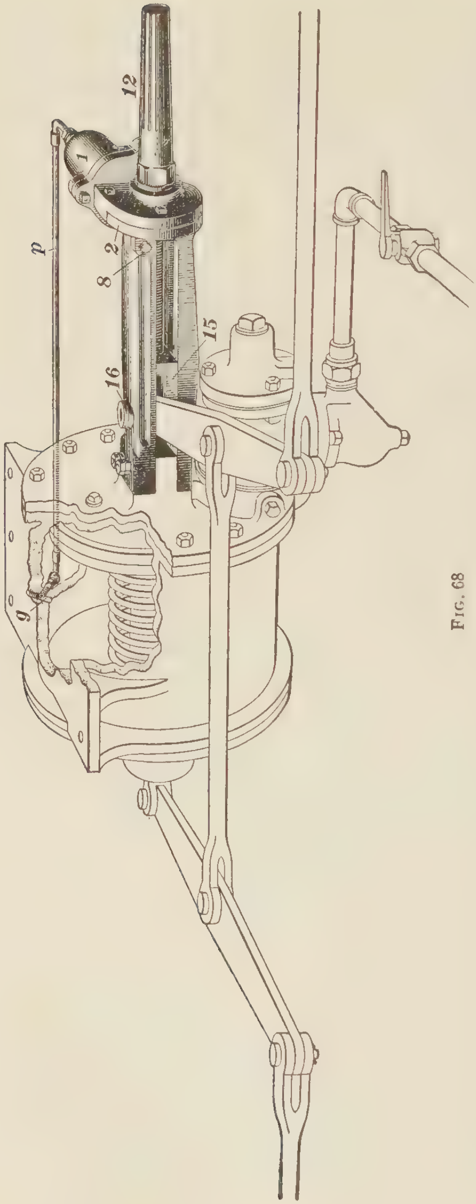


Fig. 68

service reservoir through port b, as before. This cycle of operations is repeated whenever usage or leakage reduces service reservoir pressure below the standard value.

70. The Automatic Slack Adjuster.—*Standing travel* is the distance through which the piston travels to apply the brake on a car that is standing; *running travel* is the distance through which the piston travels to apply the brake on a car that is running. Running travel is greater than standing travel and is due to slack in loose-fitting brasses, to the shoes pulling down on the wheels, to play between boxes and pedestals, to clearance between kingbolts and center castings, and to everything that increases lost motion in the brake rigging under the

influence of the motion of the car. Standing travel can be regulated by hand adjustment, and running travel can be indirectly governed, within limits, by allowing for the difference when adjusting the hand travel. Running travel can be actually regulated under working conditions by using a *slack adjuster.*

71. Fig. 68 is a general view of the Westinghouse **slack adjuster** applied to a brake cylinder, as indicated in the storage air-brake plan of Fig. 66. Fig. 69 illustrates details of the mechanism. The underlying principle of the device is that a hole is tapped in the brake cylinder and a small pipe *p*

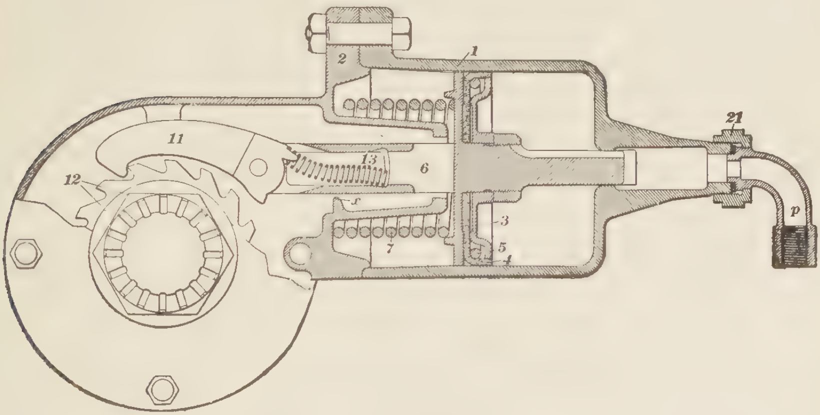


Fig. 69

screwed in it to connect the brake cylinder with the slack adjuster. When the piston travel exceeds a certain predecided amount, it uncovers the tapped hole to the live end of the brake cylinder, permitting some of the brake-cylinder air to pass into the small slack-adjuster cylinder, shown at *2*, Fig. 68, and in detail in Fig. 69.

In Fig. 69, admission of brake-cylinder air to the space behind piston *3* forces the piston and the attached pawl *11* to the left, the pawl dropping on to ratchet wheel *12*, which is mounted on a screw connected to crosshead *15*, Fig. 68. When release of the brakes places the brake-cylinder adjuster port on the atmospheric side of the brake piston, the air in

the adjuster cylinder escapes to the atmosphere and adjuster spring *7* forces piston *3* and pawl *11* back to normal position, the pawl turning ratchet *12* and screw part of a revolution; just before stopping, a heel on the pawl engages shoulder x, which raises the pawl clear of the ratchet wheel so that hand adjustment will not be interfered with. The result of this clockwise movement of the screw, Fig. 68, is to move the cylinder end of the brake lever nearer to the slack adjuster, thereby pulling all brake shoes nearer to their wheels so that the piston will not have to travel so far in order to apply them. To create considerable clearance so that a set of new brake shoes can be installed, the extension *12*, Fig. 68, is turned in a counter-clockwise direction; to take up slack rapidly by hand, extension *1* must be turned in a clockwise direction. If a set of new shoes is given proper clearance, the slack adjuster will keep the running travel correct throughout the life of the shoes. To get the best results, the two cylinder levers must make the same angle with the axis of the brake cylinder.

AUTOMATIC AIR BRAKES

INTRODUCTION

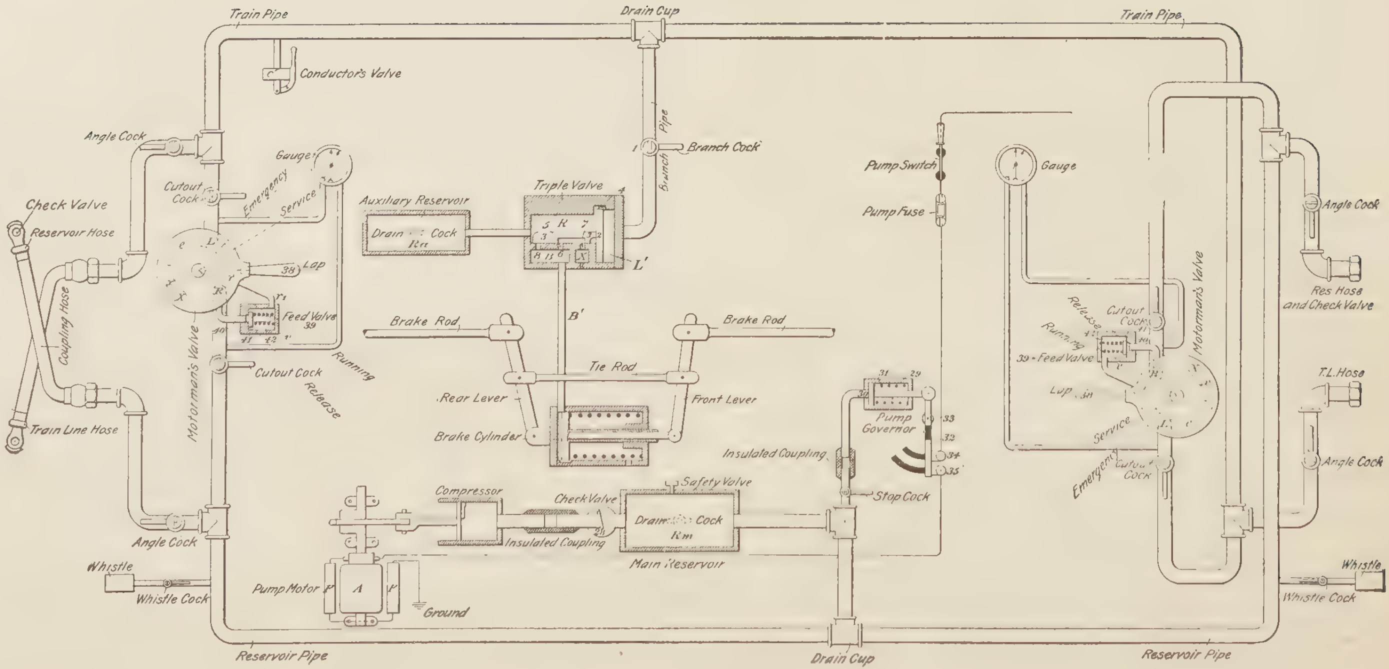
72. In train work, *automatic air brakes* are generally used because they are safer, especially on trains of more than two cars. If a train with straight air breaks into two parts, the air brake is useless and the hand-brakes must be applied on both sections. If the train has automatic air brakes, each section will come to a stop at about the same rate and there will be little danger of disaster. Again, comparatively long trains can be braked much more smoothly with automatic air because the brakes apply practically simultaneously on all cars, whereas with straight air there may be enough difference to cause bumping or stretching. In automatic air brakes, the air that does the braking is supplied from a small auxiliary reservoir on each car and the movement of the air from the auxiliary reservoir to the brake cylinder is controlled by a triple valve so that when

the engineer's valve is operated the brakes are applied to all cars simultaneously.

The automatic air-brake devices used on electric trains are in most cases the same as those used on steam trains, but, owing to the substitution of electricity for steam as a motive power, certain devices must be modified. In steam practice, the compressed air is supplied by a steam-driven air pump on the engine; the air is compressed into a main tank located on the engine and the pressure in the tank is controlled by a pump governor also located on the engine. On electric trains on which all motive power is developed on a single car, the arrangement is the same as on the steam train except that the air pump is driven by an electric motor and air pressure is controlled by an electric governor. Where each car of an electric train must be a complete motive-power and air-brake unit capable of operating alone or on any train combination, the arrangement is a little different. An automatic air-brake motor car has all the devices found on one equipped with straight air brakes with the addition of the auxiliary reservoir and triple valve, the functions of which can be understood by a consideration of Fig. 70. The only devices that have not been explained in connection with the straight air-brake equipment are the triple valve and the engineer's valve, which is a little different from that used on straight air cars. Fig. 70 is designed merely to illustrate the operating principles of automatic brakes and no attempt is made to show the actual details of the various parts; a complete description, including all the constructional features of the various devices, is beyond the scope of this treatise.

DESCRIPTION OF PARTS

73. The Triple Valve.—When valve *3* of the triple valve is in the position shown in the diagram, Fig. 70, air from the train pipe can pass into chamber L', thence through feed-groove *4* and chamber R to the auxiliary reservoir R_a. Train-pipe air will then feed into the auxiliary reservoir until its pressure is the same as that of the train



Train Pipe
Drain Cup
Train Pipe
Conductor's Valve
Pipe
Branch
Branch Cock
Angle Cock
Gauge
Cutout Cock
Emergency
Service
Check Valve
Reservoir Hose
Triple Valve
Auxiliary Reservoir
Drain Cock
Ra
Lap
Feed Valve
39
Coupling Hose
Motorman's Valve
Cutout Cock
Running
Release
Brake Rod
Brake Rod
B'
L'
Tie Rod
Rear Lever
Front Lever
Brake Cylinder
Train Line Hose
Pump Switch
Pump Fuse
Gauge
Angle Cock
Res Hose
and Check Valve
Cutout Cock
Release
Running
39 - Feed Valve
Lap
Motorman's Valve
Service
Emergency
T.L. Hose
Angle Cock
Pump Governor
Insulated Coupling
Stop Cock
Safety Valve
Compressor
Check Valve
Insulated Coupling
Rm
Main Reservoir
Angle Cock
Whistle
Whistle Cock
Pump Motor
Ground
Whistle
Whistle Cock
Reservoir Pipe
Drain Cup
Reservoir Pipe

Fig. 70

pipe, under which condition the pressures are said to have *equalized*. The pressure in chamber R is then the same as in L' and the triple valve is said to be in *release position*, because the brake cylinder is in communication with the atmosphere through pipe B', chamber B, port *6*, cavity in slide valve *3*, port *7*, and exhaust chamber and port X. If for any reason air is drawn from the train pipe, thereby reducing the pressure in the train pipe and in chamber L' of the triple valve, auxiliary-reservoir pressure in chamber R will force triple piston *2* and slide valve *3* to the right; this will first close feed-groove *4* so that auxiliary-reservoir air cannot flow back into the train pipe; then the flat part of the slide valve *3* will close port *6* and then open port *8* so that auxiliary-reservoir air can flow into the brake cylinder by way of chamber B and pipe B', thereby setting the brake. This is called *service position*, because it is used to produce a service stop. In order to release a brake that has been thus applied, it is necessary to raise the pressure in the train pipe, and hence in triple chamber L', above that in chamber R and the auxiliary reservoir, so as to force the triple piston and slide valve back to release position, to recharge the auxiliary reservoir.

74. The Engineer's Valve.—The engineer's valve used with an automatic air-brake equipment places the operations of raising or lowering the train-pipe pressure within the control of the motorman. The device marked motorman's valve, Fig. 70, is a conventional sketch showing the general principle. Exhaust ports X and x in the valve seat connect together and open directly to the atmosphere; ports R and r do not connect to each other except through *feed-valve 39*. Port R opens to the reservoir pipe and L to the train pipe. By means of circular cavity e in the rotary part of the valve, the motorman can establish any desired connection between the valve seat ports.

75. In the figure, the valve handle *30* is shown in *lap position*, the only position in which it can be installed or removed. Lap position is used when it is desired to hold

temporarily to the condition that has been established in the braking system. For example, if it is desired to hold a car or train on a grade, the train is stopped and the valve handle moved to lap position, in which all valve ports are blanked so that there can be no movement of air through the braking system.

76. If the valve handle be moved one notch to the right of lap position—to *service position*—cavity *e* establishes connection between train-pipe port *L* and service-exhaust port *x*, allowing train-line air to escape gradually to atmosphere. This gradual reduction of train-line pressure causes the triple valves to move to service position, resulting in a *service application* of the brakes throughout a train.

77. On moving the valve handle as far to the right as it can be forced (*emergency position*) cavity *e* connects train-line port *L* to emergency exhaust port *X*, allowing train-line air to discharge to atmosphere with a rush that causes the triple valves to move to emergency position where the auxiliary reservoirs equalize with the brake cylinders almost instantly, thereby immediately setting all brakes with full force. In the conventional triple valve of Fig. 70 no emergency attachments are shown.

78. Movement of the valve one notch to the left (*running position*) causes cavity *e* to establish connection between train-line port *L* and charging port *r*. In this position, if the difference between main-reservoir line and train-line pressures exceeds 20 pounds, main-reservoir pressure will lift feed-valve *41* against the feed-valve spring *42* and feed into the train line. Main-reservoir air will continue to feed into the train line until train-line pressure plus the tension of spring *42*, usually 20 pounds, is able to seat the feed-valve. The difference between main-reservoir and train-line pressures is called *excess pressure*. On steam trains, the governor maintains main-reservoir pressure at 90 pounds and the excess-pressure valves or feed-valves are set to keep train-line pressure at 70 pounds. On electric trains employing electric governors that do not cut in or out until a certain

minimum or maximum pressure is attained, however, the excess pressure is necessarily variable. The feed-valve is operative only on running position. If on any position usage or leakage of air reduces train-line pressure below its standard value, as soon as the engineer's valve is returned to running position main-reservoir pressure will open the feed-valve and recharge the train line to standard pressure. As long as the engineer's valve is on running position, all triple pistons are released and all brake cylinders connected to atmosphere so that any tendency of train-line or triple-valve leaks to cause brakes to creep on is offset by the ability of the main reservoirs to supply leaks through the feed-valve.

79. To release brakes promptly after an application, the valve handle is moved to the extreme left to *release position;* here cavity e covers ports R, r, and L and main-reservoir air rushes into the train line through the large and direct opening thus created. Train-line pressure being thus rapidly raised above that of the auxiliary reservoirs, the triple-valve pistons promptly move to release position, allowing the air in all brake cylinders to discharge to atmosphere.

FEATURES OF TRAIN HANDLING

80. Definitions.—The act of reducing train-line pressure is referred to as a *train-line reduction* or simply a *reduction.* A *service reduction* causes a *service application*, which produces a *service stop.* An *emergency reduction* causes an *emergency application*, which produces an *emergency stop.* An emergency reduction may be due to operation of the engineer's valve, as described, or to a train parting or a hose bursting. *Charging* the train line refers to bringing an empty train line up to standard pressure. *Recharging* the train line refers to restoring standard pressure reduced by making a reduction. *Overcharging* the train line refers to allowing its pressure to exceed standard value when recharging. Overcharging the train line tends to do away with *excess pressure.*

81. Making a Service Stop.—In making a stop, an initial reduction of 5 to 7 pounds is made; any less than this may be insufficient to move all brake pistons beyond their leakage grooves, in which case the air delivered by the auxiliary reservoirs through the triple valves to the brake cylinders is wasted. An initial reduction exceeding 7 pounds is not recommended, as it is liable to result in a shock to the train. In the single-application method of stopping, the initial reduction is followed by a series of lighter ones, the braking force being kept on until the train stops. In the two-application method, the initial reduction is followed by a series of lighter ones until the application is such that if held by lapping the valve, the train would stop several car lengths short of the desired point; before reaching this point, however, the brakes are released and the train permitted to roll into the station at reduced speed, when a mild graduated application will stop it at the exact point desired. A given total reduction followed by a full release constitutes one application irrespective of how many times the engineer's valve is moved to service position and back to lap to make the given total reduction. The two-application method is well adapted to close stops, where platform and car gateways must register. After making the first application, the valve is returned to lap position. The second application must follow the first so closely that if the valve is held on release or running position any longer than is necessary to release the triple valves, the train-line pressure will increase considerably above that in the auxiliary reservoirs, which will not have time to equalize through the small triple piston feed-grooves. This condition would mean a loss of air and time in making the second application, because the train-line pressure must be reduced below auxiliary-reservoir pressure in order for the triples to operate.

82. Making an Emergency Stop.—When danger requires the quickest possible stop, sand is applied to the rail and the valve is thrown to emergency position and *left there* until the train stops or the danger is past, because if thrown

to lap position too soon after an emergency reduction, rush of train-line air from the rear of a long train is liable to kick off the forward brakes; on short trains, such action is not probable. Emergency stops may be produced not only by regular operation of the engineer's valve, but by the parting of a train, bursting of an air hose, or by operation of a safety valve, called the *conductor's valve*, that is located in a conspicuous place in passenger coaches and is supposed to be operated by any one in case of trouble not known to the motorman.

83. Value of Excess Pressure.—Excess pressure is provided to insure prompt movement of the triple pistons to release position. After an application, train-line pressure is below auxiliary-reservoir pressure and the triple pistons are on lap position. To force the pistons of a lot of triple valves in good order to release position, standard train-line pressure is sufficient; but when a triple shows a tendency to stick, it is often necessary to admit main-reservoir pressure of 90 pounds into the train line. A tank of given size will hold more air, by weight, at 90 pounds per square inch than 70 pounds, so that carrying 20 pounds excess pressure virtually amounts to increasing main-reservoir capacity without increasing the size of the main reservoir. By carrying an excess pressure, air is efficiently stored at higher pressure and efficiently used at a lower pressure sufficient to meet all requirements.

84. Releasing Brakes.—Releasing brakes consists in recharging the train line by placing it in communication with the main-reservoir line through the engineer's valve. When recharging the train line, great care must be taken not to overcharge the train line and thereby destroy excess pressure. If the engineer's valve is left on release position too long, main-reservoir and train-line pressures will equalize. To avoid such a condition, the valve is left on release position just long enough to release the triples when it is placed on running position, so that the recharging may be completed through the excess-pressure valve.

ELECTRIC BRAKES

85. Various methods have been devised for operating brakes on electric cars by means of electricity, but so far **electric brakes** have been used but little in comparison with air brakes. They are all more or less complicated and have not proved to be as reliable or as easily controlled as compressed-air brakes. In most systems the current for operating the brakes is obtained by changing the connections so as to make the motors act as generators, thus making use of the energy stored in the car to supply the power used in braking. This is an economical method, but it throws additional work on the motors, and if they are already loaded to the limit it may cause overheating. This source of current supply allows the application of the brakes even though the trolley may be off the line, but it is obvious that the car can never be brought to a dead stop on a grade by means of such brakes because in order to generate current the motors must be in motion; the hand-brake must, therefore, be applied after the car has slowed down. In the American electric brake, described later, current is taken from the trolley so that the car can be stopped and held on a grade by means of the electric brakes alone.

GENERAL ELECTRIC BRAKE

86. The **General Electric brake** is dependent on the generator action of the car motors. Current generated by the motors is passed through coils wound on a disk-shaped magnet supported by the motor frames; opposite these magnets are armatures in the form of iron disks mounted on the car axles and rotating with them. Excitation of the stationary magnets causes them to attract the rotating armatures, thereby producing friction effective in stopping the car. The value of the braking current is within the control of the motorman up to a limit fixed by an automatic limit switch, which weakens the motor fields when the braking current exceeds the value for which the limit switch is set. The brake-controlling devices are within the regular operating

controller and consist of extra cylinder segments and fingers, together with an auxiliary switch that insures that the motors may always have their fields and armatures connected in the proper relation to generate, irrespective of the position of the reverse handle and of the direction of the car movement. The brake devices are put into action by advancing the controller handle beyond the regular off-position, an amount dependent on how hard it is desired to apply the brake.

WESTINGHOUSE ELECTRIC BRAKE

87. The **Westinghouse electric brake** also depends on the generator action of the car motors, but the brake itself differs widely in method of application from the one just described. The braking current passes through a coil c, Fig. 71, provided with a core terminating in poles to which are attached track shoes a, a'. Normally, the track shoes are supported a short distance from the rails by springs d, d', but

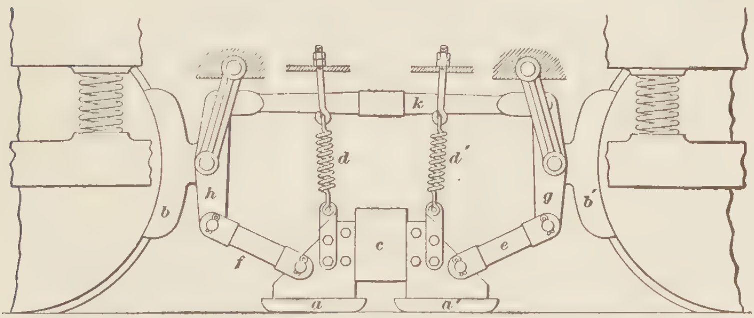


Fig. 71

on sending current through coil c the track shoes are drawn to the rail with great force, thereby tending to stop the car; simultaneously, through levers e, f, g, h, and rod k attached to the track shoes, the regular car brake shoes b, b' are forced against their respective wheels, thereby applying a second braking force.

The electrical connections are so arranged as to permit of using either the car starting coil or the car heaters as

resistance for regulating the braking current. By using the heaters for brake-current regulation, the heat dissipated is utilized for car-heating purposes. In summer, this system of regulation would make a car uncomfortable, so that on closed cars a switch is provided to enable either the heaters or starting coil to be used.

AMERICAN ELECTRIC BRAKE

88. The **American electric brake** has several features not found on other electric brakes. At speeds above 4 miles an hour, the braking current is due to the generator action of the motors and to a small line current. At lower speeds, the braking current is supplied from the line, a special relay automatically determining which source of power is to be used. The braking pressure applied to the regular car brake shoes, is due to a solenoid with a plunger so designed that the pull is practically constant throughout its travel. The braking current is applied through a controller standing beside the regular controller, the two being so connected electrically that abuse of the car equipment is prevented. With the brake applied, the regular car controller cannot introduce operating current, and with the power controller applied in full, application of the brake controller will interrupt the motor current before any braking force acts. On account of a special separate excitation feature, the braking ability is independent of the position of the reverse handle and of the direction of motion of the car. Should the brake be applied without the power controller having been thrown to the off-position, it is necessary to return the power controller to off-position before the brake can be released and motor current again introduced.

MULTIPLE-UNIT SYSTEMS
(PART 1)

INTRODUCTION

COMPARISON OF TRACTION METHODS

1. So far, all the descriptions of electric-car equipments have applied to cars that are operated separately, as in ordinary street traffic. With the extension of the application of electricity to elevated, underground, and interurban roads, there arises the problem of operating cars combined to form trains, as in ordinary steam-road practice. Trains may be operated by means of electric locomotives, in which all the propelling power is concentrated at one part of the train; in this case there is no propelling power on the individual cars making up the train. Or, each car may be provided with its own motors and the propelling power thus distributed throughout the train. A modification of the latter method is to have part of the cars equipped with motors and formed into trains with cars not so equipped. For example, a train might be made up of five cars, three with motors and two without, the train being arranged with the cars in the following order: Motor car, coach, motor car, coach, motor car. In such a train, therefore, the motive power would be applied at three points instead of the front end only, as would be the case if an electric locomotive were used.

A locomotive must have sufficient adhesive force and exert sufficient tractive effort to operate the whole train. The available adhesive force is that due to the portion of the weight of the locomotive that rests on the drivers; the locomotive, therefore, must necessarily be heavy to give sufficient

adhesive force and prevent slipping of the wheels. If each car is provided with motors, a large part of the total weight of the train rests on driving wheels and a large tractive effort is secured without concentrating a great amount of weight at any one point. Electric locomotives are desirable for certain lines of work, particularly in mining operations, where it would be hardly practicable or in fact necessary to equip each car or a number of cars in a train with motors. They are also used in connection with manufacturing plants and for hauling steam trains through tunnels, as, for example, in the Baltimore tunnel.

SEVERAL MOTOR CARS PER TRAIN

2. General Conditions.—For the operation of elevated or underground trains in cities, the standard practice in America is to use trains made up of cars, each equipped with motors. The conditions under which these trains operate are more exacting than on a cross-country road, because the stops are much more frequent, and as it is necessary to run a large number of trains at close intervals, the problem of starting and stopping the trains in minimum time becomes important. Trains of this character after making a stop must get under headway quickly, and in order to accelerate the train, a powerful effort is required during the period of acceleration. If the train is operated by a locomotive, it is difficult to obtain rapid acceleration, because the weight resting on the drivers is not sufficient to prevent slippage of the driving wheels. With the motive power divided among a number of driving wheels, and with the greater part of the whole weight of the train resting on the drivers, rapid acceleration can be procured without slippage.

The use of individual motor cars admits of a train being made up of any number of cars, and as each car is equipped with its own driving power, the motor capacity is increased or decreased in proportion to the number of cars to be operated. This allows the size of the trains and the number of motors in operation to be readily changed to suit traffic conditions.

When an electric locomotive is used, the same motors are operated whether or not the locomotive is hauling cars to its full capacity, and as the locomotive must be large to operate a full train, it follows that when a few cars only are used the motors are operated at the low efficiency corresponding to a light load. With the use of motors on each car, safety is insured, because the motive-power units are divided and widely separated, and an accident to one of them does not interfere seriously with the operation of the train. All track and structure stresses are less than with locomotives, because of the more uniform distribution of weight.

3. Definition of Multiple-Unit System.—The system of operating trains of cars, each fully equipped with electric motors, brakes, etc., was first developed by Mr. Frank T. Sprague, and has been called by him the **multiple-unit system.** Mr. Sprague's definition of the multiple-unit system is as follows:* "It may be described as a semiautomatic system of control which permits of the aggregation of two or more transportation units, each equipped with sufficient power only to fulfil the requirements of that unit, with means, at two or more points on the unit, for operating it through a secondary control, and a 'train line' for allowing two or more of such units, grouped together without regard to end relation or sequence, to be simultaneously operated from any point in the aggregation." This definition will be more clearly understood after a description of the multiple-unit system has been given.

4. Elementary Operating Principles.—Suppose three ordinary surface trolley cars to be completely equipped, but that instead of running the car wires from controller to controller in each car and letting them end there, the wires are run from end to end, tapping off to each controller and putting suitable couplers on the ends, as indicated in Fig. 1, so that the car wires on one car can be made continuous with those on the next, thus producing an elementary multiple-unit train. The main-current motor

*Transactions American Institute of Electrical Engineers, Vol. XVI.

wires will run from one end of the train to the other, irrespective of the length of the train; the train can take current from one trolley pole, or third-rail shoe, or from all the poles or shoes at once, and it can be operated from any controller on any car, whether this car be in the middle or on the end of the train. Every car will do its own share of the work, so that the whole train will start, run, and stop as quickly as a single car. There are, however, several

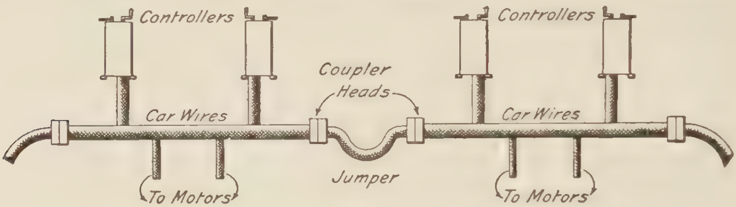


FIG. 1

strong objections to a multiple-unit system of this kind: As each controller would be compelled to handle the current required for the whole train, a large and clumsy controller would be necessary; the car wiring would have to be extra heavy to carry the total train current; and it is probable that a satisfactory coupler to transmit such currents would be impracticable. Finally, in case of short circuits or grounds on the car wires of any car, the cut-out devices that would meet all conditions would necessarily be complicated.

5. In the multiple-unit system as actually applied these objections have been overcome, and there are at present two prominent systems. The General Electric Company, who acquired the Sprague patents, has brought out a multiple-unit system, which it designates as type M control, that is entirely electrical in its operation. The Westinghouse system for the same purpose is electropneumatic in its operation, compressed air being used to actuate the controllers on each car, and the valves controlling the compressed air being operated electrically.

6. In both these systems there is placed on each platform of every motor car a small controller, called the *master*

controller, while every car has a *train line*, consisting of a number of small insulated wires made up into a cable and provided with couplers at each end of the car. All the master controllers are connected to this train line, which handles the small current required for the operation of the main controllers. When the train is made up, the train line extends from one end to the other, connecting all the master controllers and the mechanisms that they operate, so that all the main-circuit controllers, and hence motors, can be operated from any master controller. The master-controller circuit is distinct from the main-motor circuit and carries but a small current. The master controller has a number of positions, on some of which the motors are in series and on others in parallel, like an ordinary controller; it is extremely important, therefore, that the main-controller operating devices should respond to the notches of the master controller simultaneously and with precision; for, if the main-motor controllers should feed up at different rates, a condition might arise where the motors on some cars would be in series and those on others in parallel, thus causing trouble.

Each car is provided with its own braking outfit, consisting of an engineer's valve, motor compressor, governor, triple valve, tanks, etc., so that if called on to run alone, it can do so. When a multiple-unit train is started, each car starts, and there is no bumping or jerking as when a train of cars is started by means of a locomotive. There is little strain on the couplings between the cars, and there is therefore little tendency for such trains to break in two. On some roads, for heavy high-speed traffic, the equipment intended primarily for the operation of multiple-unit trains has been used even though the cars are operated singly. On such cars, the amount of current taken becomes so large that it has been found safer and better to operate the main controller through a master controller on the platform. This simplifies the main car wiring, does away with the large controller that would otherwise be necessary on the platform, and also reduces the risk from fire because the main controller and wiring can be arranged and protected so as to reduce the danger of setting

fire to the cars in case of short circuits or other defects. The system is also well adapted to the operation of electric locomotives, large hoists, or other service involving the use of large currents, and particularly for those cases where the controller must be placed some distance from the motors.

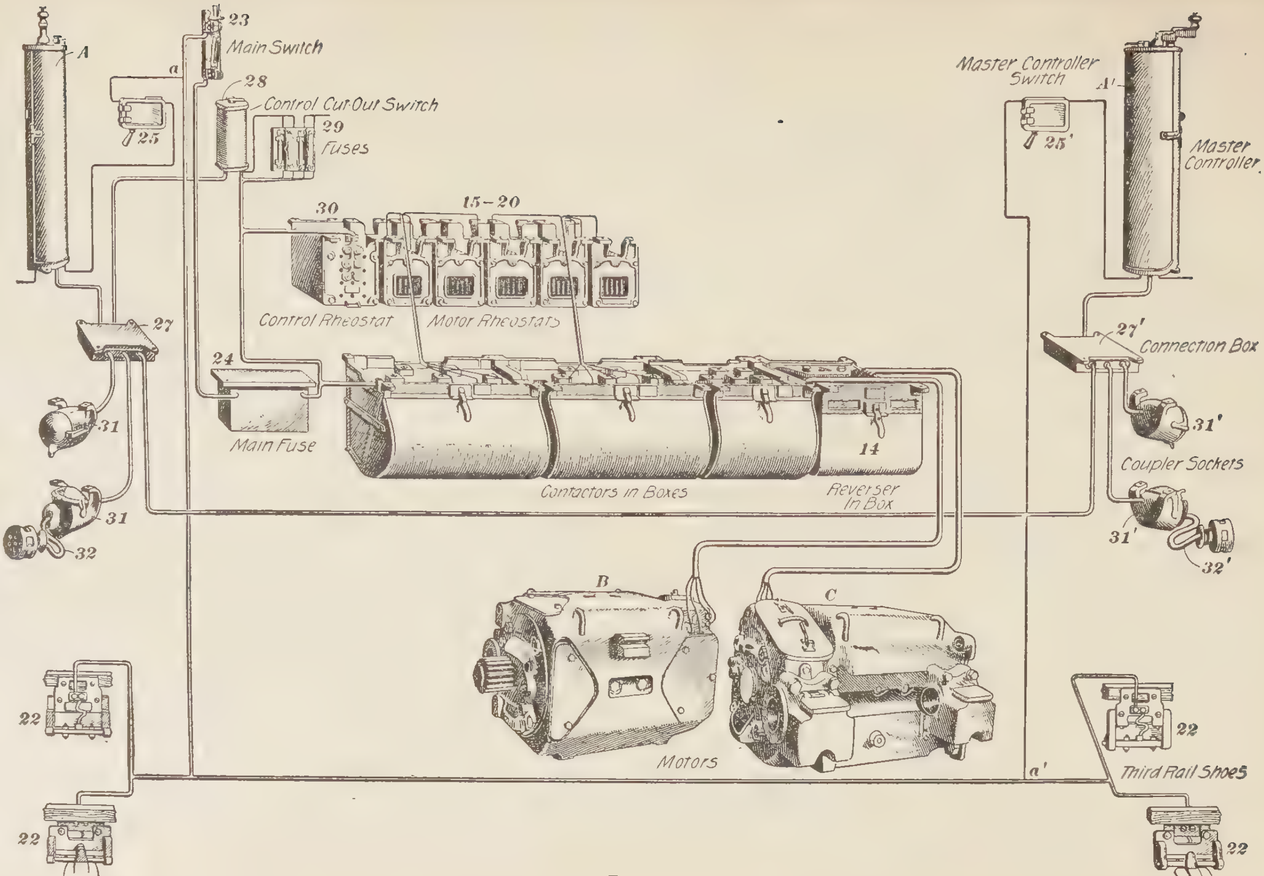
SPRAGUE-GENERAL ELECTRIC MULTIPLE-UNIT SYSTEM

TYPE M CONTROL

DESCRIPTION OF APPARATUS

7. General Features.—The multiple-unit system of control as developed by the General Electric Company, and known as their **type M control,** is wholly electrical in its operation. Fig. 2 shows a general view of the motor-control apparatus installed on each car, and will serve to give an idea of the system as a whole. The master controllers A, A' are placed on the platforms and control the current that operates the main-motor controller. The latter, instead of being a single device, consists of thirteen electromagnetic switches, or *contactors*, as they are called, and a reversing switch, called a *reverser*, all located under the car in protective housings, as indicated in the figure. The movements of these switches and the combinations of connections that they make are controlled by the master controllers A, A'. The current that passes through the master controller energizes the operating coils of the contactors and has nothing to do with the main-motor current. The starting resistance used to limit the current flowing through the motor is mounted in the frames *15–20* in the usual manner, and the main current controlled by the contactors is supplied to the motors B, C through suitable cables.

The main current flows from the third-rail collecting shoes *22*; or if a trolley wire is used, the contact shoes will be



A
23
Main Switch
a
28
Control Cut-Out Switch
25
29
Fuses
30
15–20
Control Rheostat
Motor Rheostats
27
24
Main Fuse
31
31
32
Contactors in Boxes
14
Reverser
In Box
B
C
Motors
22
22
Master Controller
Switch
A'
25'
Master
Controller.
27'
Connection Box
31'
Coupler Sockets
31'
32'
a'
22
Third Rail Shoes
22

FIG. 2

replaced by the trolley wheel. From *22*, the current passes through the main switch *23*, by means of which the main current can be cut off; it next passes through the main fuse *24*, which is of the copper-ribbon, magnetic, blow-out type. From *24*, the current passes to the contactors, reversing switch, and resistance grids, as described later, and finally through the motors B, C to ground. At the points a, a', the control circuit for each controller is tapped to the main wire from the contact shoe, and switches *25*, *25′* allow the interruption of control current through master controllers A, A', respectively. From the controllers, the various wires making up the control cable pass to the *connection boxes* 27, 27′, which afford a ready means of connecting or disconnecting the various parts of the control circuit, thus facilitating installation and making it easy to split up the control circuit in case it becomes necessary to locate some defective part. From 27, the local control-circuit wires pass through a cut-out switch *28*, by means of which all the operating coils on a car can be cut out in case defects should develop. The fuse block *29* holds four enclosed fuses for the protection of the control-circuit operating coils, and the high-resistance rheostat *30* is connected in series with different parts of the control circuit so as to limit the control current to the allowable amount no matter how

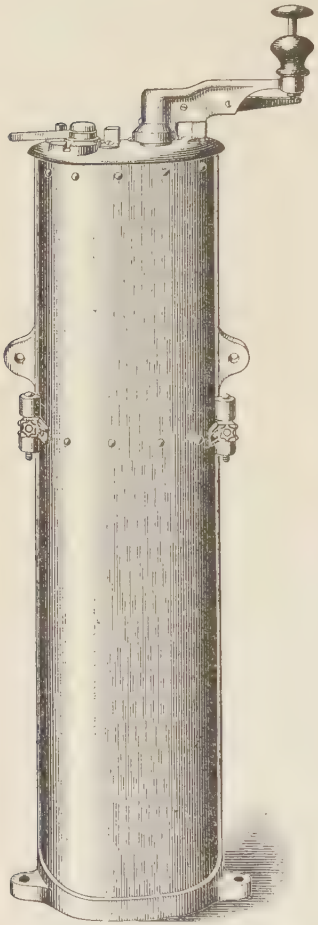


Fig. 3

many operating coils may be in service. The coupler sockets for making the connection of the control circuit from one car to the next are shown at *31*, *31'*; jumpers for connecting the couplers of abutting cars are shown at *32*, *32'*.

The foregoing will give a fair idea as to the general layout of the type M control system. After the various devices have been considered by themselves, the connections and method of operating will be described.

8. The Master Controller.—Fig. 3 shows the General Electric C6 master controller with the cover in place, as it appears on the car. The controller, as a whole, is similar in its external appearance to an ordinary type K controller, being about the same height but considerably narrower and occupying much less room. It is located on the platform against the dash rail or vestibule front, in about the same manner as the controller on an ordinary street car.

Fig. 4 shows the controller with the cover removed. The operating handle is shown at *1* and the reverse handle at *2*. The operating handle is not removable, as on an ordinary controller, but the reverse handle is, and when removed the main shaft is locked so that it cannot be turned. The operating handle turns shaft *3*, on the end of which is a gear *4* that meshes with gear *5* on the shaft of main cylinder *6*. The main cylinder is constructed in the usual manner, except that the contact segments *7* are considerably narrower than on an ordinary controller, the current handled being comparatively small. Contact segments *7* engage with contact fingers *8*, mounted on a finger board in the usual manner. The iron pole piece *9* carries the insulating arc deflectors *10* that pass between adjacent contact segments whenever the hinged pole piece is swung into its usual position. The blow-out coil is indicated at *11*. All current handled by the master controller passes through this coil and sets up a magnetic field that suppresses arcing at the contacts. The main cylinder is provided with the usual star, or index, wheel *12*, which, in connection with a spring-actuated pawl, gives decision to the notches.

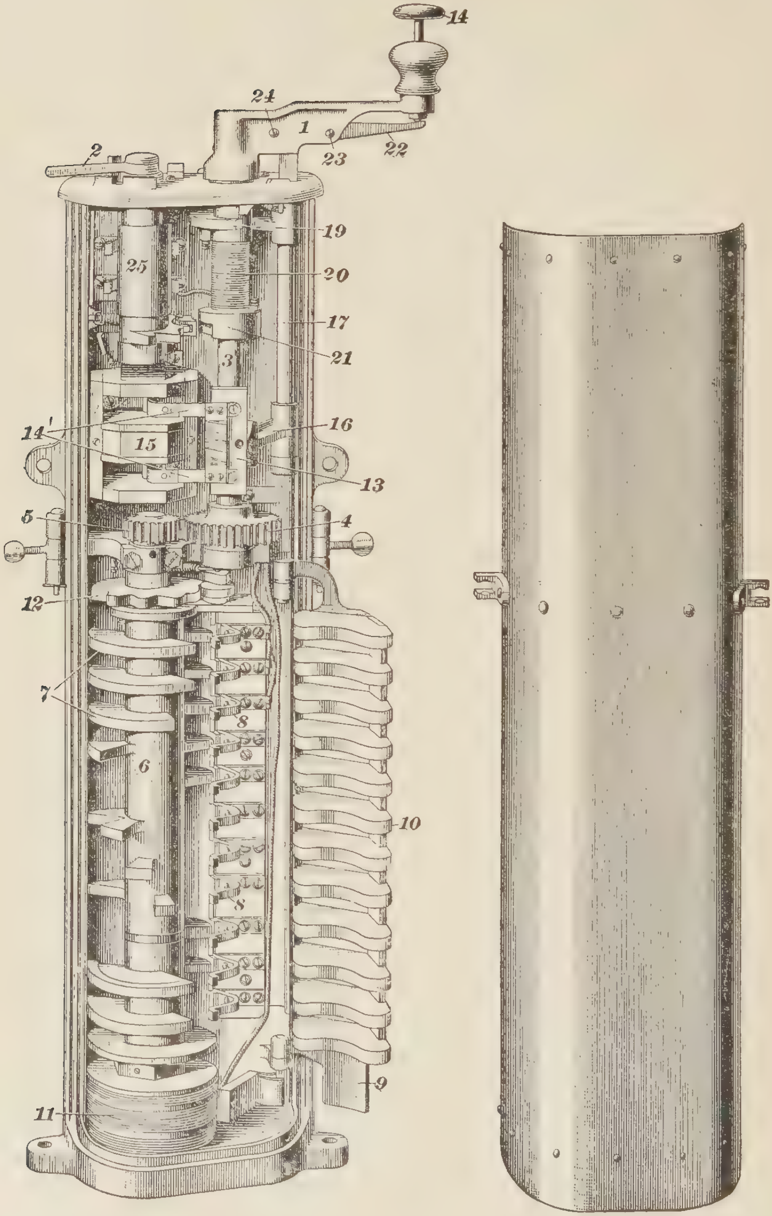


FIG. 4

9. The C6 master controller contains a safety switch *13* not usually found on ordinary controllers; it is provided as a factor of safety in high-speed work. To operate the controller and supply current to the motors, it is necessary that the motorman keep knob *14* depressed; if the knob is released, all power is at once cut off from the motors by the opening of safety switch *13*, irrespective of the position of the operating handle; nor can power be applied to the motor circuit again without first restoring the operating handle to the off-position. Should an accident befall the motorman, causing him to release knob *14*, the train will be automatically stopped. On this account knob *14* is sometimes called the dead man's knob, or handle.

Switch *13* consists of an insulating block on which are mounted two fingers *14'* connected together by a metallic strip. When the switch is closed, the fingers touch contacts mounted in the recesses above and below the auxiliary blowout coil *15* cased in insulating material. The insulating block that carries fingers *14'*, *14'* is mounted on the end of an arm *16* fastened to the rock-shaft *17*, which is acted on by a spring that normally holds it in such a position that fingers *14'*, *14'* are swung out from their respective contacts. All the current in the operating circuit has to pass through the safety switch, and unless this switch is closed by fingers *14'*, *14'* being swung in until they touch their contacts, the control circuit is inoperative and no current can be supplied to the motors. The movements of the rock-shaft *17* and switch *13* are controlled by a cam *19* that has a notch engaging a short arm extending from the rock-shaft; cam *19* is mounted loosely on the main shaft. A spiral spring *20* has its upper end attached to *19* and its lower end to collar *21*, which is firmly fixed to the main shaft *3* and rotates with it. If handle *1* is turned, without pressing down knob *14*, the main shaft *3* and drum *6* are turned, but cam *19* does not turn, because it is mounted loosely on the shaft and is prevented from turning by the projecting arm on rock-shaft *17*. Under these conditions, therefore, spring *20* merely twists or untwists, and since switch *13* is not closed,

the control circuit is inactive. If, however, knob *14* is pressed down before handle *1* is turned, a small dog, or catch, is pressed down and locks cam *19* to shaft *3*. This dog is forced down by means of lever *22*, hinged at *23*, which engages a second small lever hinged at *24* and mounted within the handle. When cam *19* is thus locked to the main shaft, it forces the rock-shaft *17* to rotate through a small angle just as soon as handle *1* is moved from the off-position, thereby closing switch *13* and allowing current to pass through the controller. Spring *20* is placed in position at the factory under considerable tension, so that there is always a tendency for relative movement between cam *19* and collar *21*. When handle *1* is moved around and *14* pressed down, cam *19* is locked to the shaft and hence moves around with collar *21*. There is therefore no twisting action on the spring and no change in the initial tension. Suppose, however, that knob *14* is released after the handle has been moved around from the off-position; the dog engaging *19* is released, and *19* is then free to revolve on the shaft independently of *21*. As soon as *19* is released, the tension on spring *20* causes it to fly to its initial position, and switch *13* at once opens, thus cutting off all current from the control circuit. Before the catch operated by *14* can be again made to engage with cam *19*, handle *1* must be brought back to the off-position, thereby restoring the tension in spring *20* to the original amount. The safety device not only cuts off the current in case of accident to the motorman, but it prevents current from being thrown on, unless all operating devices are in the starting position. For example, if the motors were in parallel and the power cut off by releasing *14*, it could not be turned on again with the motors in the parallel position; the handle would have to be brought to the off-position and the motors worked up to the parallel position through the various resistance steps and series connections.

10. The small cylinder *25* in the upper left-hand corner of the controller is the *reverse cylinder*, which controls the

movements of the reverser *14*, Fig. 2, and thus determines the direction of movement of the car. The handle *2*, Fig. 4, of the reverse cylinder cannot be removed until it is moved to the off-position, and this motion of cylinder *25* operates an interlocking device that locks the main shaft *3* so that it cannot be moved. The removal of the small reverse handle therefore prevents the operation of the car from that controller, so that this small handle in effect constitutes a key to the operation of the train and is taken off and carried by the motorman in case he leaves the controller.

The general construction and operation of the master controller is very similar to that of an ordinary magnetic blow-out controller, the principal distinguishing features being the automatic safety switch and the lighter construction of the current-carrying parts. Some of the controllers are built without the automatic safety feature, as on some roads it is not considered essential.

11. Controller Positions.—Fig. 5 is a sketch of the master controller top. There are ten marked positions for the operating handle, but only two of these, *5* and *10*, indicated by marks longer and heavier than the others, are

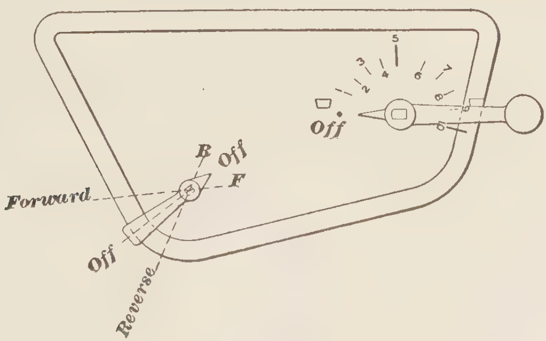


Fig. 5

running positions. On position *5*, the car motors are in series with all resistance cut out; while on position *10*, they are in parallel without resistance. The reverse handle has the usual three positions—forward, off, and reverse—the

arrangement of connections being such that the position of the reverse handle indicates the direction of movement of the car.

12. Contactors.—Fig. 6 shows a pair of contactors, the construction of which will be understood from Fig. 7. The design is such that two or more contactors can be grouped together on a common base, as in Fig. 6, thereby simplifying the heavy main-current connections. In Figs. 6 and 7, corresponding letters have the same signification: *a* is the operating coil wound in two sections; *b* is a movable core or plunger; and *c*, a corresponding stationary core. On the lower end of *b* is hinged a frame *d* that presses on arm *e* through spring *f*. Arm *e* carries on its upper end a contact tip *g* that, when the arm is in the position of Fig. 7, presses against stationary contact tip *h*, thereby closing any circuit of which they may be a part. One main terminal of the contactor is shown at *i*, Fig. 7, and the other at *j*. At *k*, Fig. 7 (*a*) and (*b*), is indicated a blow-out coil consisting of a few turns of heavy bare conductor. Iron pole pieces *l* bolted to both ends of the blow-out coil core *m* direct a strong magnetic field across the region of tips *g* and *h* so that arcing at the contact tips is suppressed. All smoke and gases pass out through a specially provided flue, of which *n* and *o* are the top and bottom walls.

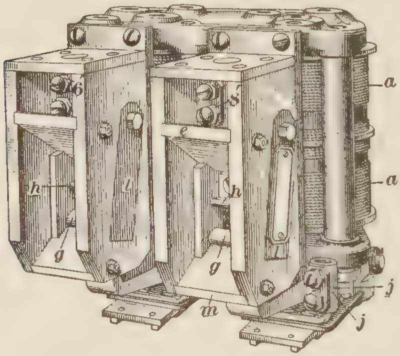


FIG. 6

13. The operation of the contactor is as follows: In Fig. 6, the contactors are open. The instant that current from the control circuit energizes operating coil *a*, it draws plunger *b* up to the position shown in Fig. 7 and the main-motor current enters the contactor at terminal *i*, passes

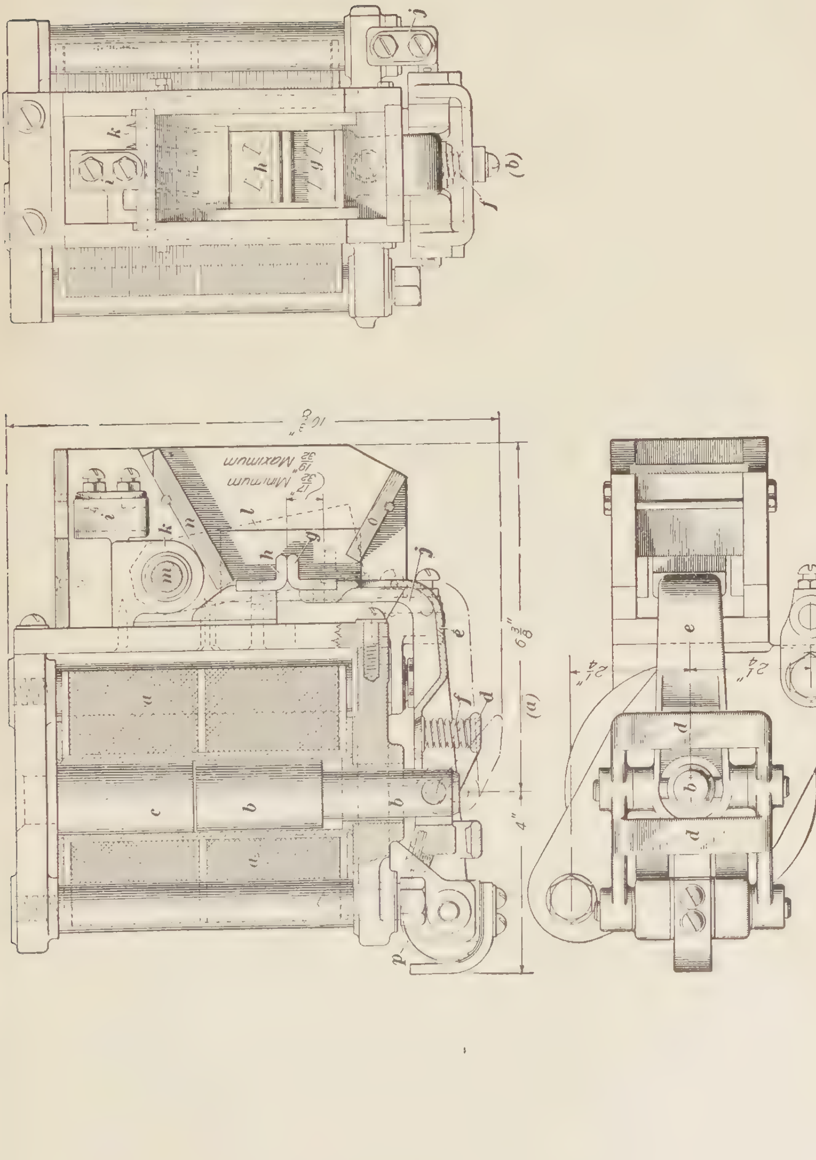


FIG. 7

through blow-out coil *k* to top contact tip *h*, thence through bottom tip *g*, arm *e*, shunt *p*, and the contactor frame to terminal *j*, which is fastened to the frame, on to the next device in circuit by way of the wire connecting to terminal *j*. Spring *f* is instrumental in giving the contact tips a wiping action past each other when the contactor closes, thus making a good contact and preventing the contacts from sticking. The spring also helps gravity to release the mechanisms promptly when the current is cut off from the operating coil.

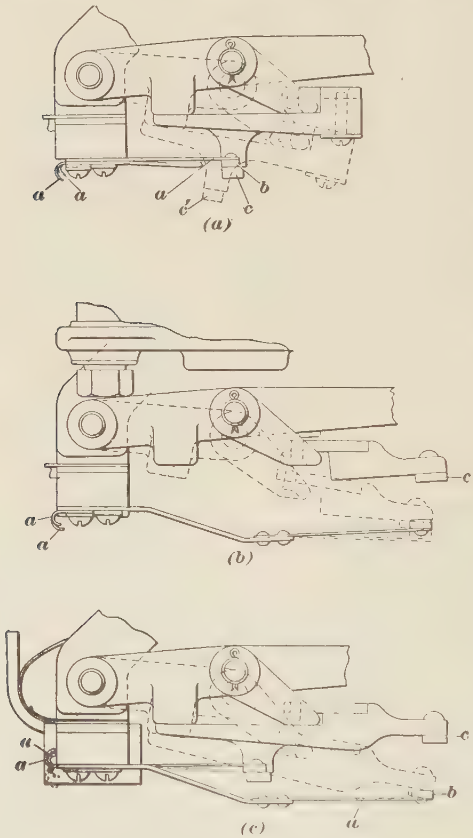


FIG. 8

14. On several of the contactors, lever arm *d* is provided with auxiliary contacts called *interlocks*. Some interlocks are so installed and constructed that they will be open when the contactor on which they are mounted is open; others are arranged so as to be closed when the contactor to which they are attached is open, and vice versa. The object of an interlock is to prevent simultaneous action of two circuits in which such action would be objectionable. The general method of attaching the interlocks is indicated in Fig. 8. Small fingers *a*, *a* (the two fingers are in line with each other

so that only one shows in the figure) are attached to the lower part of the contactor frame and carry contact tips *b*. When, in (*a*), for example, the contactor is closed, the metal crosspiece *c* makes contact with the interlock fingers, and when the contactor opens, *c* drops to position *c'*, thus opening the interlock circuit. In (*b*), the interlock is closed when the contactor opens; while in (*c*), there are two interlocks, one of which closes when the contactor closes and the other closes when the contactor opens. The interlocks are safety

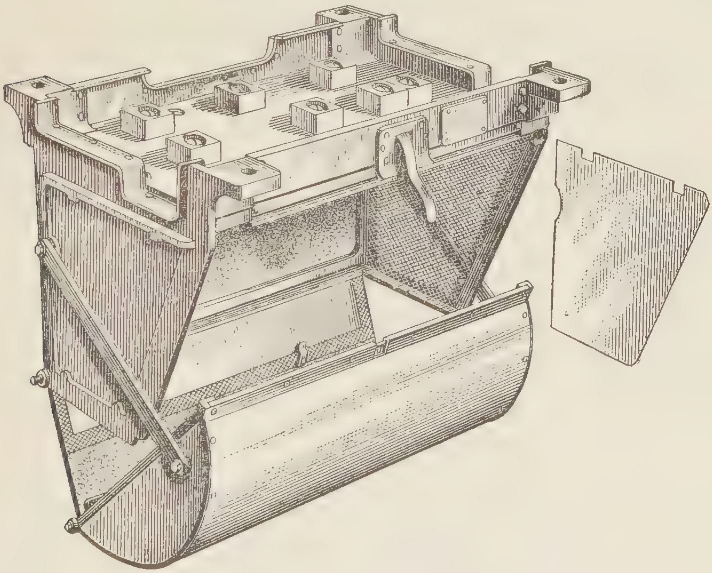


FIG. 9

devices and do not under ordinary conditions open or close the control circuit when current is flowing.

15. The location selected for the contactors is usually along one side underneath the car where they will be convenient for inspection and out of the way of other equipment parts. As a mechanical protection for contactors and reversers when installed under the car, boxes similar to that shown in Fig. 9 are used. Figs. 10, 11, and 12 show the arrangement of contactors, which are divided into three

groups and are protected by sheet-iron covers that can be dropped, as shown, to give access to them. The reverser is mounted in a casing by itself at the right-hand end.

16. The **reverser** performs the same duties as the reverse switch of an ordinary controller; that is, it controls the direction of the flow of the current through the motor armatures and thereby determines the direction of motion of the car. Each car must be equipped with a reverser, and the movements of all the reversers on a train are controlled by the small reverse switch on the master controller. Fig. 13 is a view of the DB20 reverser, which is mounted under the car

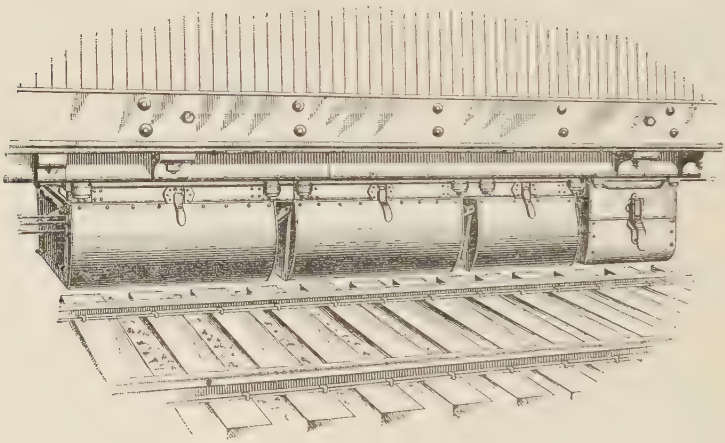


Fig. 10

in the same way as the contactors. A cast-iron rocker *a* is hinged at *b*, and on the ends of the beam are two molded insulation pieces *c*, *c* to which are attached the heavy segments *d*, *d* that carry the main-motor current; segments *e*, *e* are lighter and carry the control current only. Fingers *f*, *f* engage with the heavy segments, and *g*, *g* with the lighter ones. The rocker can be moved through a limited range by means of two solenoids, one of which is shown at *h*; a similar coil is behind *h*, the end of its plunger being shown at *k*. The plungers of the solenoids are connected to the rocker-arm through suitable links, and the movement of the rocker is

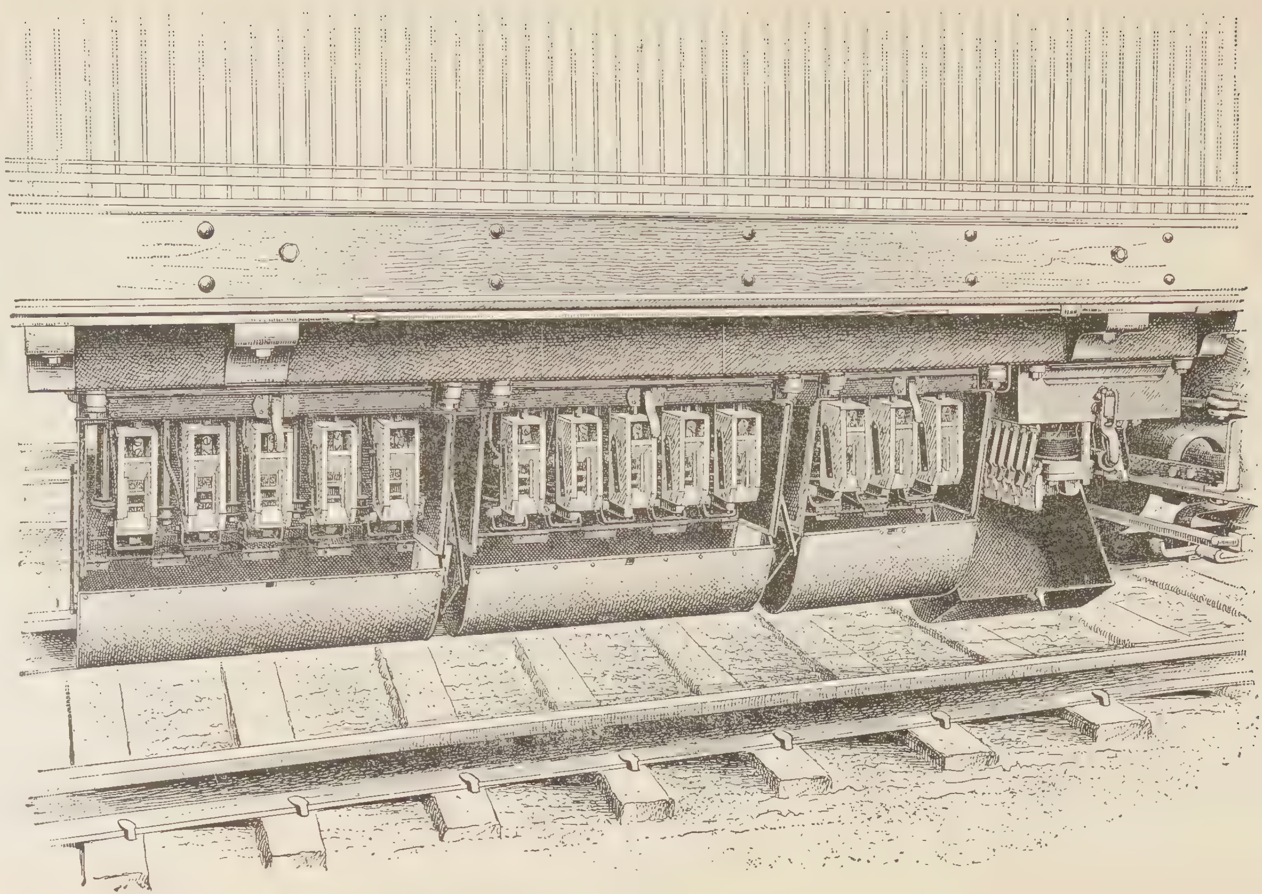


FIG. 11

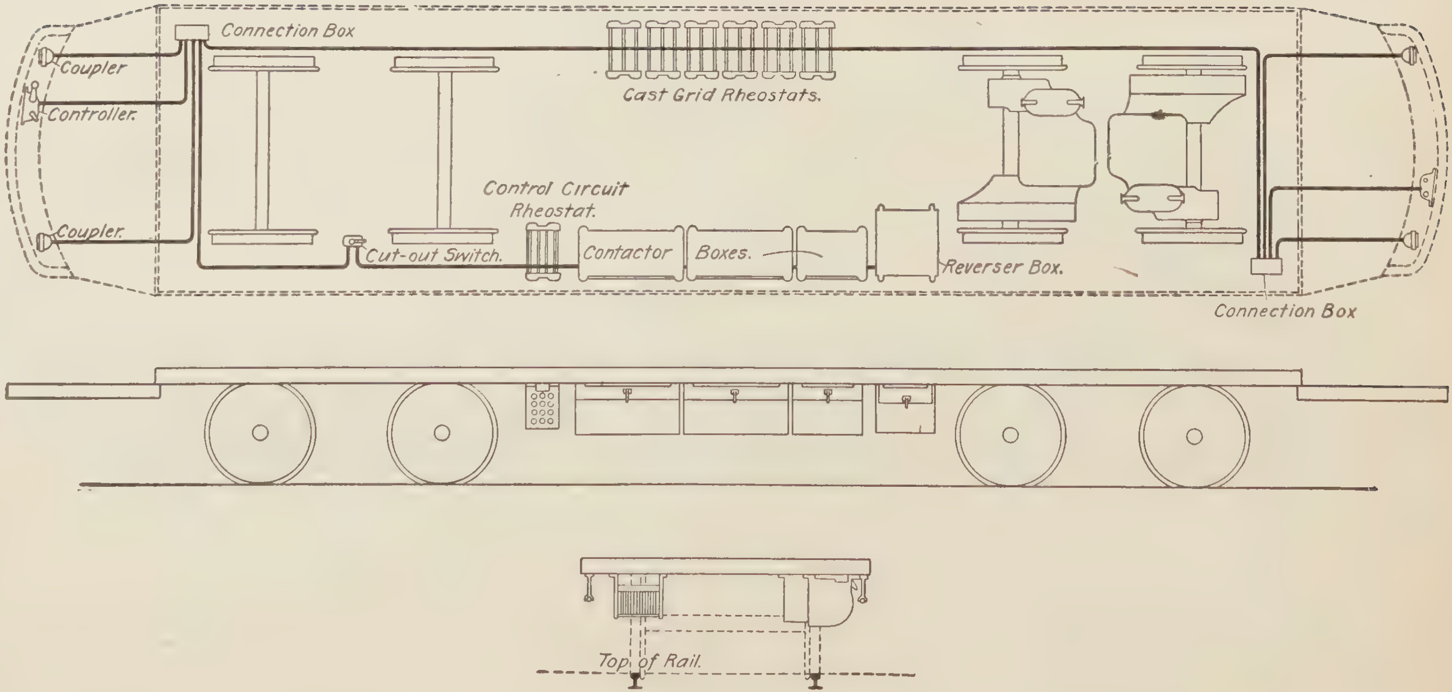

Connection Box
Coupler
Controller.
Coupler.
Cast Grid Rheostats.
Control Circuit
Rheostat.
Cut-out Switch.
Contactor
Boxes.
Reverser Box.
Connection Box
Top of Rail.

FIG. 12

limited by stops. When coil h is energized, the rocker occupies the position shown in the figure; but when the other coil is energized, the rocker is thrown over to the other position, the left-hand side being pulled toward the base of the reverser and the other side moving down, thus bringing different sets of contacts under the contact fingers. Suitable interlocks make it impossible for both coils to be energized

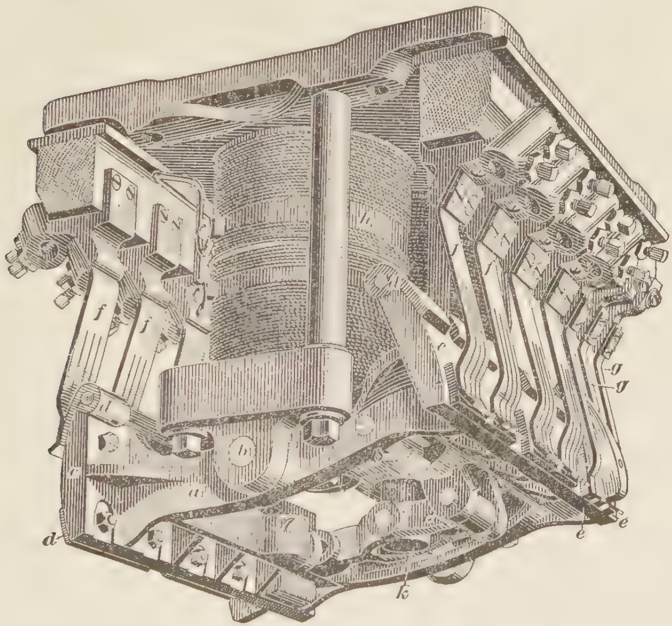


FIG. 13

at once. One position of the rocker corresponds to the forward position of the reverse handle on the master controller, and the other to the reverse position.

17. Connection Boxes.—Each car equipped with the type M control is provided with two **connection boxes**, shown at *27*, *27'*, Fig. 2, which are located under the car. Their object is to afford a simple and effective means of connecting corresponding wires of several control cables without the use of permanent splices. Fig. 14 shows the style of box

used. It is made of iron and contains an insulating base *a* on which are mounted clamps *b* for connecting the similar wires of the different control cables. Holes *c* are tapped for 1-inch pipes through which the cables enter, the ends of the wires being soldered to the small terminals *b*, *b*. In Fig. 2, there are four control cables entering the left-hand box and three entering the right-hand box, and in each box the similar wires in each cable are connected together by the clamps. The screwing of cover *d*, Fig. 14, in place renders the connection box water-tight.

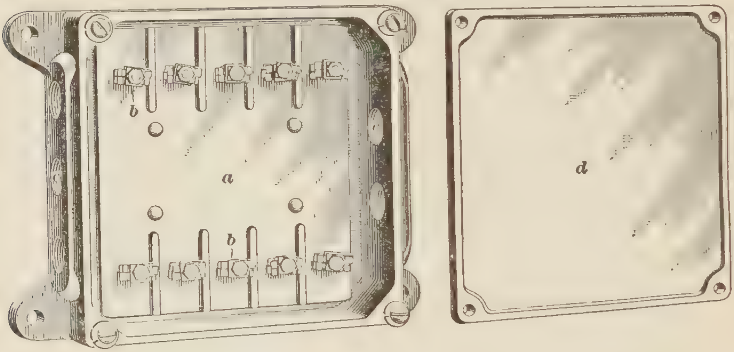


FIG. 14

18. Coupling Devices.—All cars that are to be coupled up into multiple-unit trains must be provided with means for carrying the train control wires from car to car. If cars unequipped with motors are to be used in connection with motor cars, they must be provided with means for preserving the continuity of the control cable throughout the train. Connections of the control cable from car to car are made by means of couplers consisting of *sockets* placed under each car platform or set into the dash, and a short piece of cable with a plug at each end. The piece of cable with its two plugs is called a *jumper;* Fig. 15 (*a*) shows a jumper consisting of two plugs connected by means of a piece of control cable provided with a rubber covering. Fig. 15 (*b*) shows one of the sockets, or receptacles, which is provided with

nine insulated contacts a connected to the nine train wires. The contacts are numbered *0* to *8*, inclusive, and the train wires are provided with coverings in different colors or

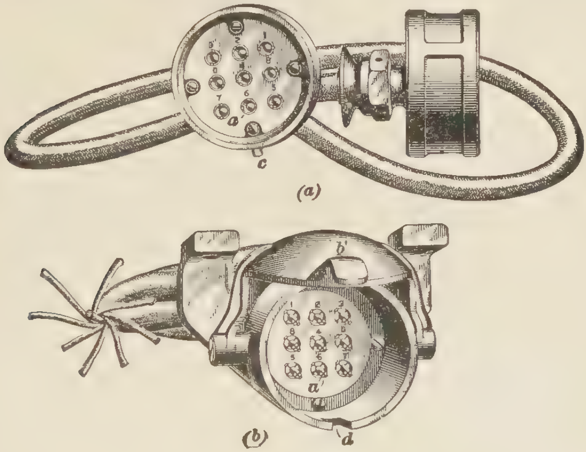


FIG. 15

combinations of colors, so that there will be no difficulty in getting the wires connected to corresponding terminals at each end of the car. The hinged cover b swings down over the front of the socket when it is not in use, thus excluding dirt and water.

The removable plugs, shown in Fig. 15 (a), are provided with nine receptacles a' into which the terminals a in the socket fit. The lug c slides into the slot d shown in (b), when the plug is inserted, and unless lug c is placed in line with d, the plug cannot be put in place; it is thus impossible to put in a plug upside down and get the train wires interconnected wrongly. The coupler sockets are provided with spring catches that hold the plugs in place against any

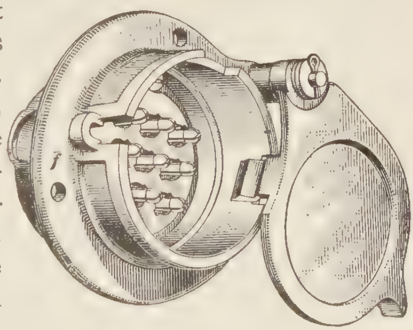


FIG. 16

stresses that arise in ordinary use, but if an undue stress is brought on the jumper, as, for example, by a parting of the train, the catches allow the plugs to pull out. It is customary to provide two coupler sockets at each end of the car, one on each side of the center line, as in Figs. 2 and 12; by using two sockets, a car can always be conveniently connected to an abutting car, because, no matter what may be the end-on relation of the cars, two sockets will always be directly opposite each other. Also, when there are two sockets on each end, one is available in case the other becomes defective, so that the double-socket equipment increases the reliability of the outfit. In order to have one socket on each end of a car meet all conditions of service, that socket must be either in the center of the end of the platform, or the single socket on opposite ends must be on opposite sides of the car, as in the case of air-brake couplings. Fig. 16 shows the style of socket used on interurban cars. The socket is set into the dash and secured to it by flange *f*.

19. Cut-Out Switch.—The object of the cut-out switch, as used with the type M control, is to provide a means of disconnecting control wires of the devices on the car from the train-line control wires. It is shown at *28*, Fig. 2, and is usually located under a car seat or in the special cab or compartment that is often provided for the control apparatus. The switch consists of a drum with nine contact strips corresponding to the nine wires of the control cable. On each side of the drum is a row of nine contact fingers, one set being connected to the incoming control wires from the connection board and the corresponding fingers of the opposite set connected to the outgoing wires leading to the control coils. When the handle of the switch is at the on-position, the contact strips on the drum connect opposite fingers and thus make the path through the switch continuous. When the handle is thrown to the off-position, the contact strips leave one set of fingers and thus place a break in each of the control wires. This prevents the devices on the car from operating, though it does not interfere in any way with the

operation of the devices on the other cars of the train. If, therefore, the motors or other operating devices on a car become defective, they can at once be cut out of service by means of the cut-out switch.

20. Control Cables.—The cables required for the equipment of a car with type M control are shown in Fig. 2. They are named and located as follows: On the front end of the car are located the No. 1 master controller and connection box connected by a short cable called the *No. 1 master-controller cable;* another short cable connecting the cut-out switch to the connection box is called the *local control cable.* The small cables running from the connection boards to the coupler sockets are called the *forward-coupler cable* or *rear-coupler cable*, as the case may be. The No. 2 master controller and No. 2 connection board are on the rear end of the car, and the cable running between them, called the *No. 2 master-controller cable*, is interchangeable with a similar cable on the front end. The *train cable* runs between the connection boxes, as shown, and the *local contactor cable* carries the control wires to the several contactors. With the exception of the cable connecting the cut-out switch to the operating coils of the reverser and contactors, the control cables contain nine wires. The main-motor cable consists of three parts, the branch running to the starting rheostat, the branch running to the reverser, and the part connecting to the motors. The relative arrangement of the apparatus may differ considerably from that shown in Fig. 2, because most

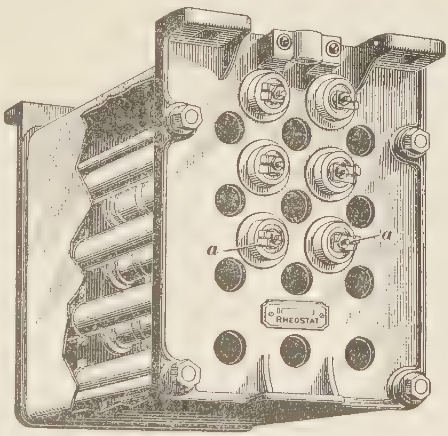


FIG. 17

of the appliances have to be placed under the car and their exact position is therefore determined by the location of other appliances, such as air-brake apparatus, brake rigging, etc.

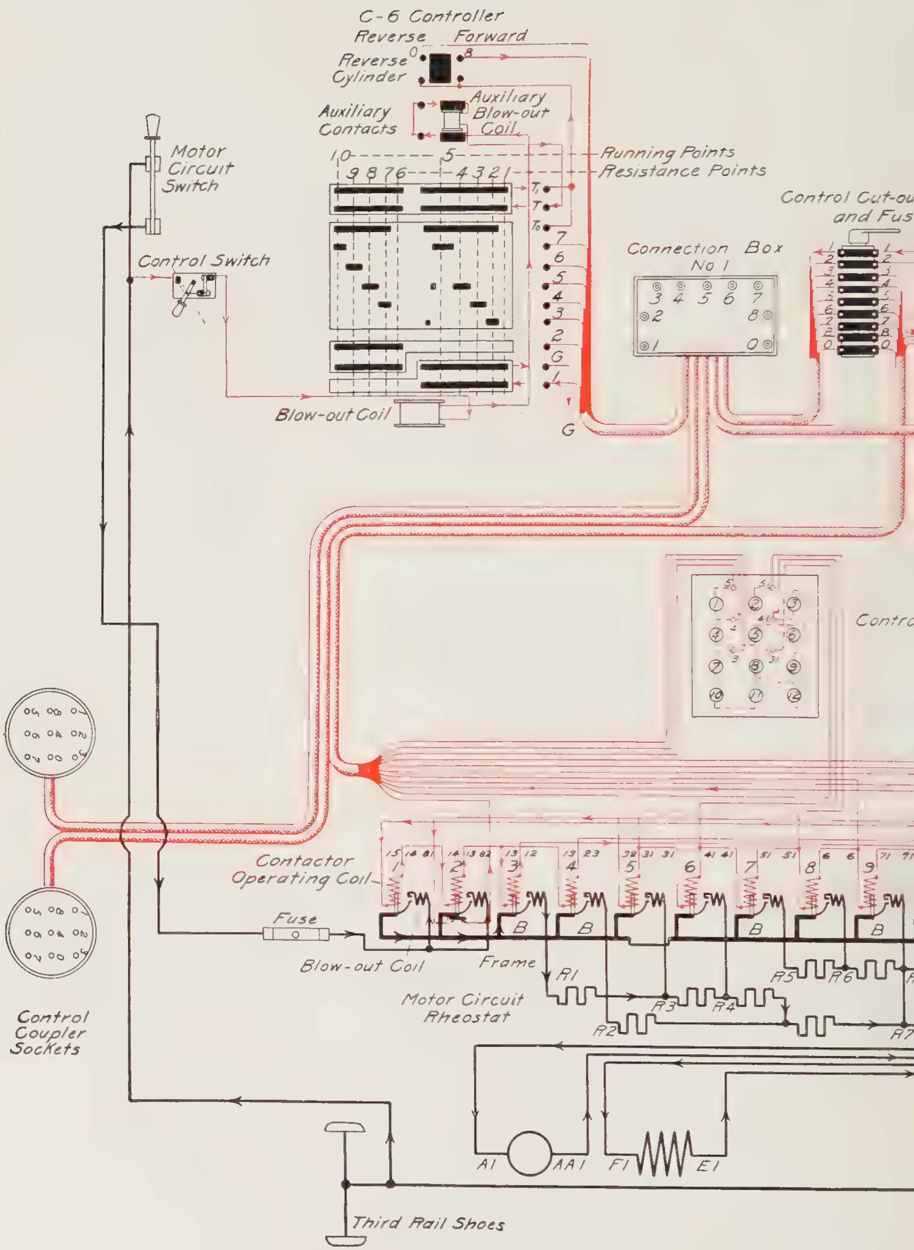
21. Control-Circuit Rheostat.—The control-circuit rheostat, Fig. 17, is made up of twelve high-resistance coils completely enclosed in a sheet-iron protecting case. The ends of the coils are brought to the outside of the case and connected to terminals *a*. The operation of the master controller cuts sections of the control rheostat out or in, according as contactor operating coils are cut in or out, thereby maintaining the control current per car approximately constant and preventing any of the contactor coils from being subjected to abnormal pressure.

22. Motor-Circuit Rheostat.—In order to prevent a rush of current through the motors at starting and secure a smooth acceleration, a rheostat must be used in the main-motor circuit as with ordinary car equipments. The rheostat is of the cast grid type and is made up of a number of units, as shown in Fig. 2. The resistance is the same in its general construction as that used for ordinary cars, so that further description is unnecessary.

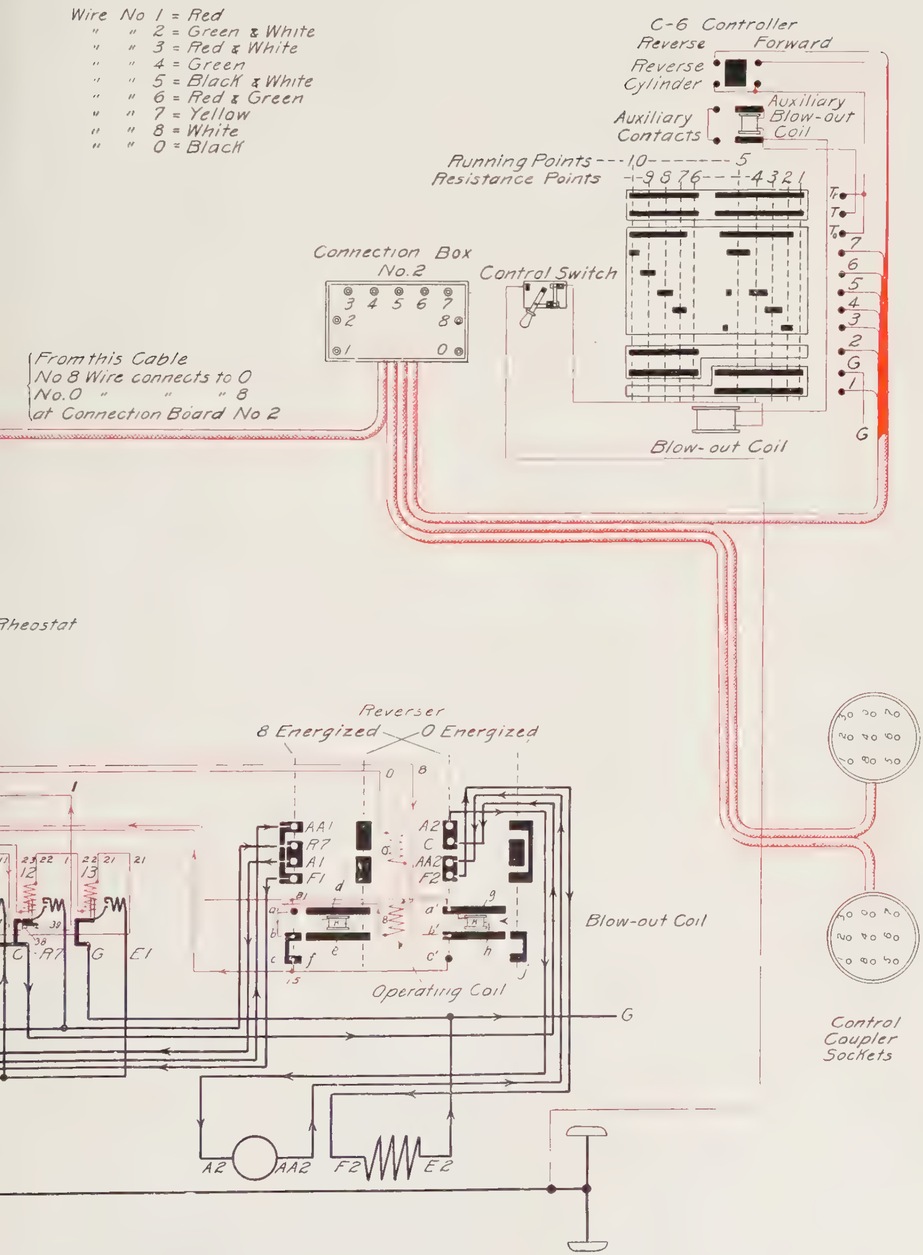
WIRING DIAGRAM FOR TYPE M CONTROL

23. General Description.—Fig. 18 is a general diagram of the wiring for two C6 master controllers operating two motors, the equipment corresponding to that shown in Fig. 2. The control-circuit wires, Fig. 18, are in red and the operating-circuit wires in black, in order that each may be more readily distinguished. The various operating devices are printed in black irrespective of whether they belong to the operating circuit or to the motor circuit.

At the top of the master controller is shown the small reverse drum with the two control wires *0, 8* connected to its contact fingers. Immediately below the reverse drum is the safety switch, with the auxiliary blow-out coil connected between the two fixed contacts of the switch. Below this is


C-6 Controller
Reverse
Forward
Reverse Cylinder
Auxiliary Contacts
Auxiliary Blow-out Coil
Running Points
Resistance Points
Motor Circuit Switch
Control Switch
Blow-out Coil
Connection Box No 1
Control Cut-ou
and Fus
Contr
Contactor Operating Coil
Fuse
Blow-out Coil
Frame
Motor Circuit Rheostat
Control Coupler Sockets
Third Rail Shoes

ue-General Electric
Control



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the operating cylinder made up of four castings; the black strips show the development of the contact segments, and all the segments on the same casting are, of course, connected electrically. Below the operating cylinder is the blow-out coil for suppressing the arcs at the contact fingers, represented by the vertical row of dots at the right. The main contacts on the reverser are shown by the heavy black bands engaged in pairs by the reverser main-circuit fingers marked *AA1*, *R7*, *A1*, *F1*, *A2*, *C*, *AA2*, *F2*. In the diagram, the operating coil to which wire *8* leads is responsible for the position in which the contacts are shown. Introduction of current to the operating coil connected to reverse wire *0* will cause the reverser contacts to shift bodily to the left. Fingers a, b, c, a', b', c' and narrow contacts d, e, f, g, h, j have to do with the control circuit. Small magnetic blow-out coils are shown at k, k. The object of these interlock contacts and fingers on the reverser is to insure that no motor current will flow through the reverser unless it is in an operating position; that is, unless the main reverser contacts are resting on their segments. The reverser must also occupy the position to give the car the required direction of motion. For example, if the train is required to move forwards, and the reverse switch of the master controller is set to the forward position, it may happen that, through previous use, the reversers on some of the cars do not occupy the position corresponding to the train movement, and these auxiliary contacts insure that the reverser will occupy the correct position before the main current is allowed to flow, otherwise certain contactors that are necessary to admit current to the motor circuit cannot operate and the car cannot take current. This will be seen when the operation of the devices is considered.

24. Operation on First Notch of Master Controller. It is assumed that the master-controller reverse cylinder is moved to the forward position and that the power handle is moved to the first position, as indicated by the vertical dotted line *1* on the development of the operating cylinder. The car or train is assumed to be operated from the left-hand

controller. As soon as the operating handle is moved from the off-position, the safety switch closes, since the dead-man's knob is supposed to be pressed down. The path of the control current is then as follows: Control-circuit switch–fuse–main blow-out coil–auxiliary blow-out coil–safety switch–finger *T*–finger T_1–finger *8* by way of reverse cylinder–*8* on connection box No. *1*–post *8* on cut-out switch–reverse operating coil *8*–reverser control finger *b*–contact segment *f*–finger *c–15–15*–operating coil of contactor *1–14–14*–operating coil of contactor *2–13–13*–operating coil of contactor *3–12–12*–operating coil of contactor *11–11–11*–interlock contact *38*–interlock contact *39–1–1*–fuse *1*–cut-out switch *1*–connection-box terminal *1*–operating-cylinder finger *1*–ground finger *G*. On the first point, therefore, contactors *1*, *2*, *3*, and *11* are operated, and the reverser is at the forward position, shown in the figure. The path of the motor current corresponding to this combination will be: Motor-circuit switch–main fuse–$<\begin{matrix}\text{contactor } 1\\ \text{contactor } 2\end{matrix}>$–frame *B*–contactor *3–R1–R3–R4–R7–R7* (on reverser)–*A1–A1–AA1–AA1–F1–F1–E1–E1* (on contactor *11*)–*C–C* (on reverser)–*A2–A2–AA2–AA2* (on reverser)–*F2–F2–E2*–ground. The arrowheads in Fig. 18 show the paths of the control current and main-motor current when the master controller is on the first notch. See also Fig. 19.

In tracing the above circuit, Fig. 18, it was assumed that the reverser already occupied the position shown in the figure and corresponding to that assumed when coil *8* is energized. Suppose, however, that the rocker had, on account of previous use or for any other reason, occupied the opposite position, so that the small interlock fingers on the reverser rested on segments *d*, *e*, and *j* instead of *g*, *h*, and *f*. The current entering at *8* would then take the path *8*–through operating coil *8*–finger *b*–segment *e*–blow-out coil *k*–segment *d*–contact finger *a–81–81*–interlock on contactor *2–82–82*–fuse–ground. There can be no current flow in the motor circuit unless contactors *1* and *2*, called *line contactors*, are closed. Current is introduced to the

reverser operating coil only when master-controller fingers T and T_1 make contact with the upper casting. If, on moving the operating handle to the first notch, the reverser happens to rest in a position corresponding to the existing position of the reversing handle, current takes the path already outlined and closes the line contactors so that motor current can flow. Should the reverse rest in the wrong position, however, control finger c is not in contact with anything and the line contactors cannot close. Reverser current does, however, take the path leading through the interlock on contactor *2*, thereby throwing the reverser to the correct position in which the line-contactor operating coils can get current. Simultaneously with the operation of the line contactors, the interlock switch on contactor *2* of course opens, thereby interrupting in a second place the circuit used for throwing the reverser to correct position and which the reverser itself interrupted at the instant of operation. Blow-out coils k, k suppress all arcing that tends to follow the interruption of the control current. Contactors *1, 2* are connected in parallel so as to reduce the current handled by each, because these contactors correspond to the trolley fingers of an ordinary controller, and the service imposed on them is more severe than on the others. Contactors *9, 10* are connected in a similar manner.

25. Operation on Last Series Notch.—As the drum is turned to positions *2*, *3*, and *4*, contactors *5*, *6*, and *7* are added to those already in operation, as can be seen by tracing out the control circuit. The result is to reduce the resistance in series with the motors. On the fifth position, which is the last series notch and one of the running notches, all of the resistance is cut out. The path of the operating current is as follows, starting from finger T on the master controller: T–T_1–T_0–finger *7*–connection-box terminal *7*–cut-out contact *7*–terminal on contactor *10–71–71*–contactor *9–6–6*–contactor *8–51–51*–contactor *7–41–41*–contactor *6–31–31*–contactor *5–32–32*–fuse–ground. The path of the reverser current remains as before, so that it is not necessary to trace it out.

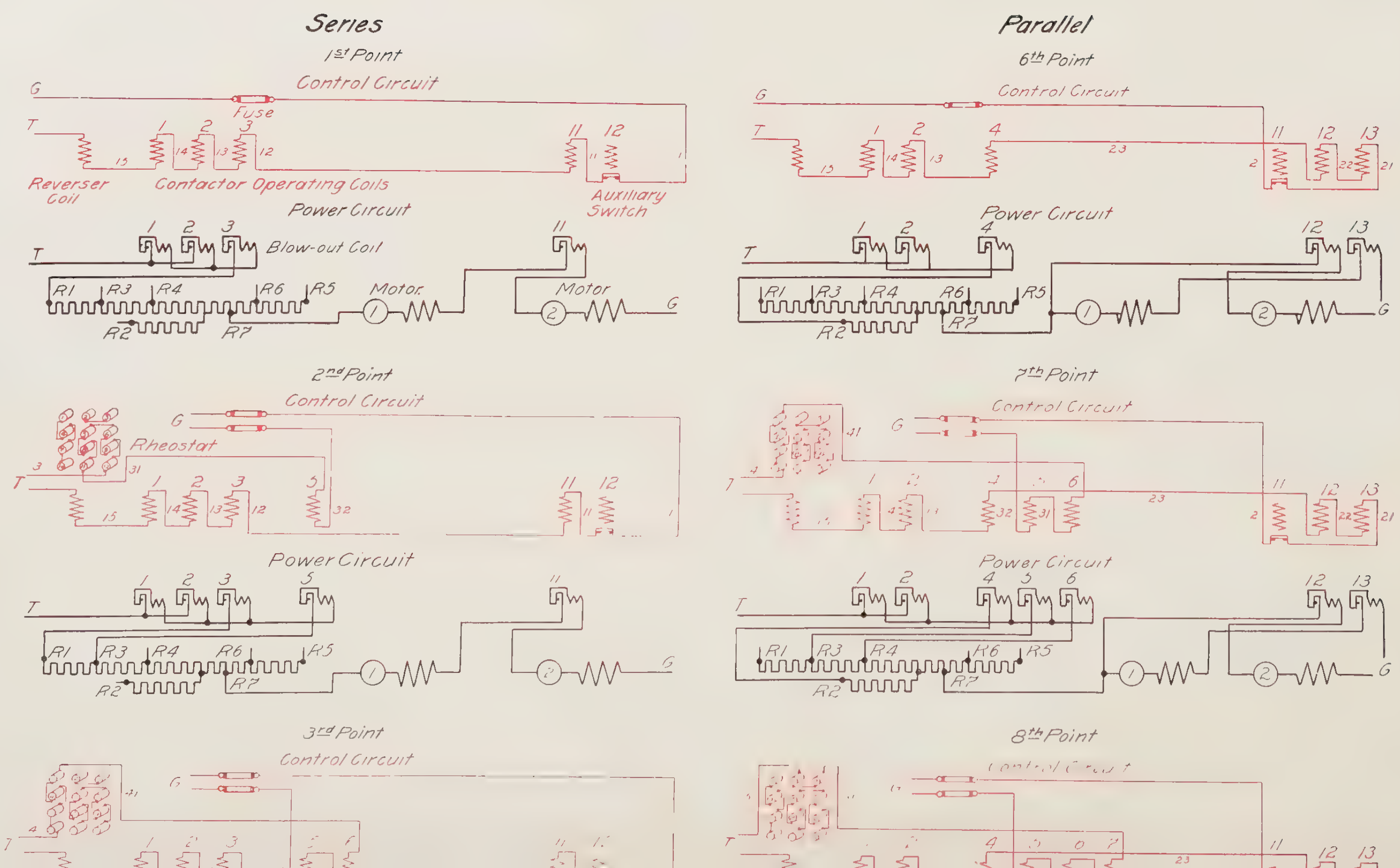
The motor current takes the path: Motor-circuit switch–fuse–< contactor *1* / contactor *2* >–frame *B B*–< contactor *9* / contactor *10* >–*R7*–*R7*–*A1*–*AA1*, etc.–ground. All the resistance is cut out and the two motors are in series.

26. Operation on First Parallel Notch.—When the controller is on position *6*, that is, the first parallel notch, the operating current may be traced from finger *T* as follows: T–T_1–reverse cylinder–*8*–*8* on connection board–*8* on cut-out switch–coil *8* on reverser–*b*–*c*–*15*–*15*–contactor *1*–*14*–*14*–contactor *2*–*13*–*13*–contactor *4*–*23*–*23*–contactor *12*–*22*–*22*–contactor *13*–*21*–*21*–interlock *37*–*36*–*2*–fuse *2*–*2* on cut-out–*2* on connection-box–finger *2* on controller–ground. This operates the reverser, or rather keeps the reverser in the position that it already had on the series notches, and operates contactors *1*, *2*, *4*, *12*, and *13*.

The path of the motor current is then as follows: Motor-circuit switch–fuse–< contactor *1* / contactor *2* >–*B*–*B*–contactor *4*–*R2*–*R7*–< *R7* (on reverser)–*A1*–*A1*–*AA1*–*AA1*–*F1*–*F1*–*E1*– / *R7* (contactor *12*)–contactor *12*–*C*–*C*–*A2*–*A2*–contactor *13*—— / *AA2*–*AA2*–*F2*–*F2*–*E2* >–ground.

The motors are therefore in parallel with two sections of the resistance in series with the circuit.

27. Operation on Last Parallel Notch.—On position 7, contactors *5* and *6* operate and reduce the resistance in the circuit by placing a resistance section in parallel with one of the sections previously inserted. On the eighth position, contactor *7* is picked up and resistance sections *R5*–*R6*–*R7* are placed in parallel with those already in use. On the ninth position, contactor *8* is picked up and resistance section *R5*–*R6* is short-circuited. On the last parallel notch, contactors *9*, *10* are picked up, thus establishing a direct connection between *BB* and the wire *R7 R7* running to the reverser and thereby cutting out all resistance. On the parallel notches, the resistance in series with the motors is, in


Series
1st Point
Control Circuit
Fuse
Reverser Coil
Contactor Operating Coils
Auxiliary Switch
Power Circuit
Blow-out Coil
Motor
Motor
2nd Point
Control Circuit
Rheostat
Power Circuit
3rd Point
Control Circuit
Parallel
6th Point
Control Circuit
Power Circuit
7th Point
Control Circuit
Power Circuit
8th Point

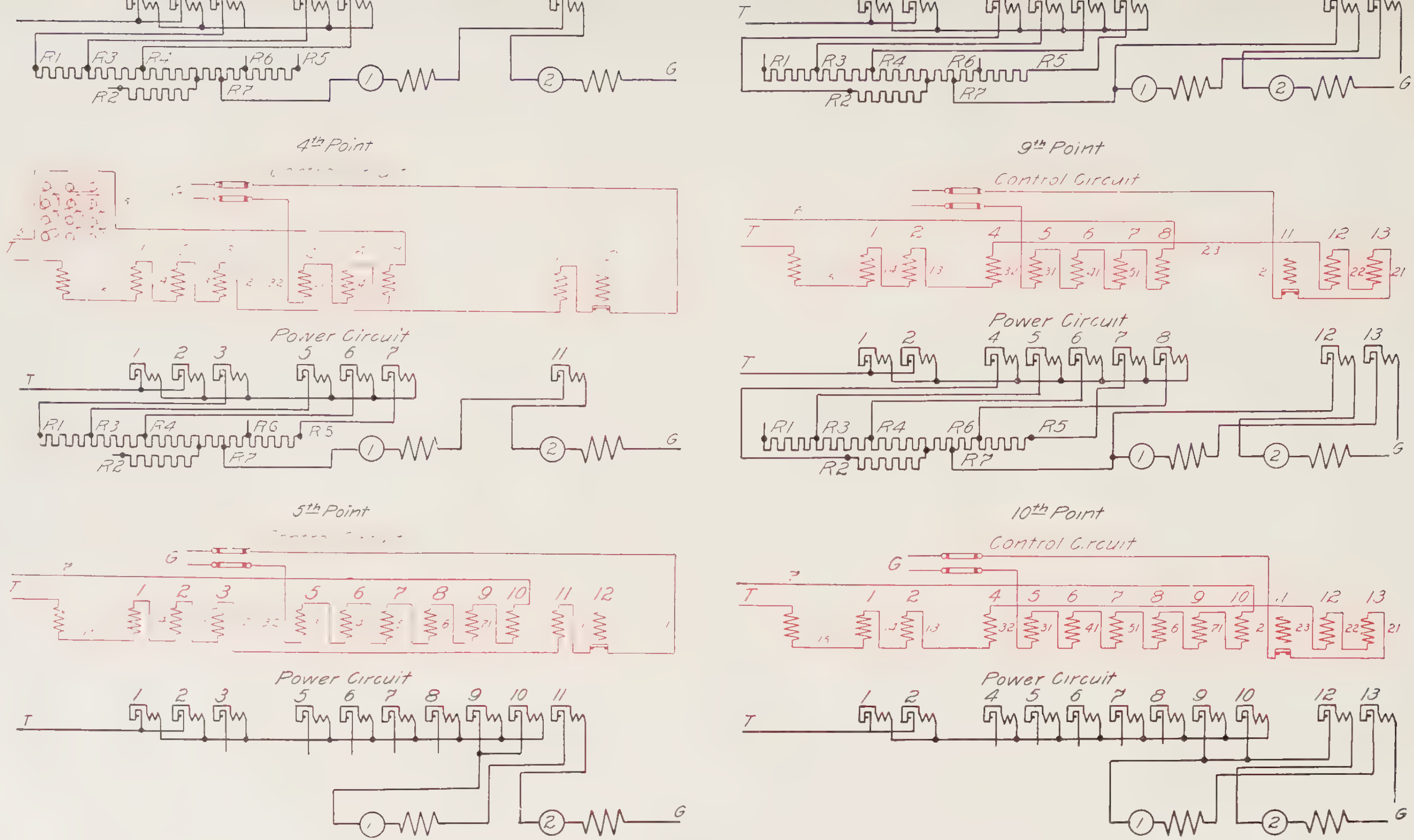


FIG. 19

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some cases, decreased by connecting sections in parallel rather than by cutting out existing sections. The advantage of this method is that, as the resistance is reduced, its carrying capacity is increased and it is better able to handle the heavy current taken by the car on the parallel notches.

As far as the final effect on the motors is concerned, the combinations effected by the movement of the master controller are practically the same as those effected by an ordinary series-parallel controller, though the master controller itself

TABLE I

Number of Notch	Contactors in Operation												
1	1	2	3								11		
2	1	2	3		5						11		
3	1	2	3		5	6					11		
4	1	2	3		5	6	7				11		
5	1	2	3		5	6	7	8	9	10	11		
6	1	2		4								12	13
7	1	2		4	5	6						12	13
8	1	2		4	5	6	7					12	13
9	1	2		4	5	6	7		8			12	13
10	1	2		4	5	6	7	8	9	10		12	13

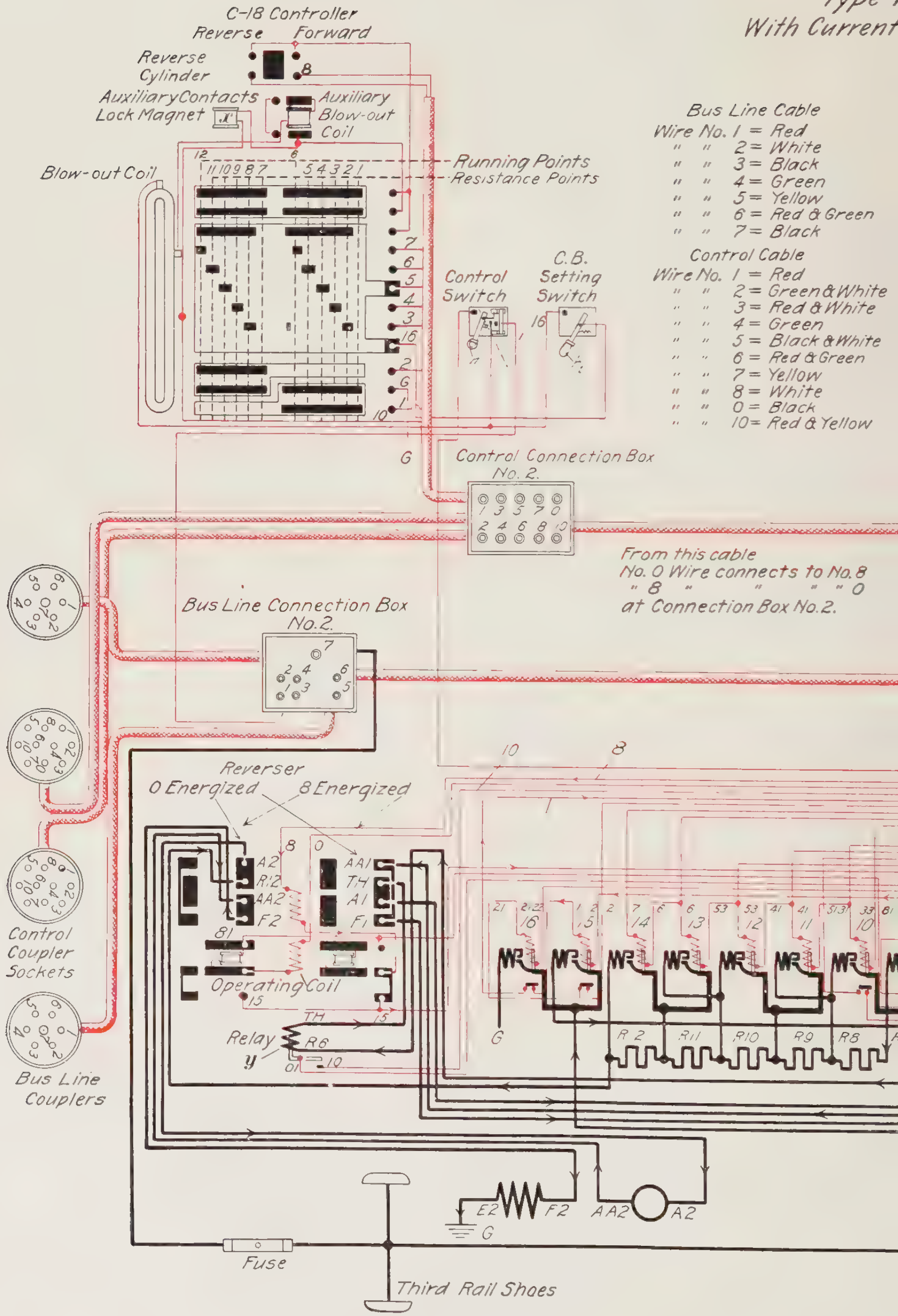
is not connected with the motors. In Fig. 18, the connections have been explained by referring to the operation of devices on one car only. Where a number of cars are coupled together, the whole train control line becomes energized, and the devices on all cars operate synchronously with those on the operating car.

28. Fig. 19 is a diagrammatic sketch of the control-circuit and motor-circuit combinations existing on all points of the C6 master controller. Table I shows the contactors in operation on each point.

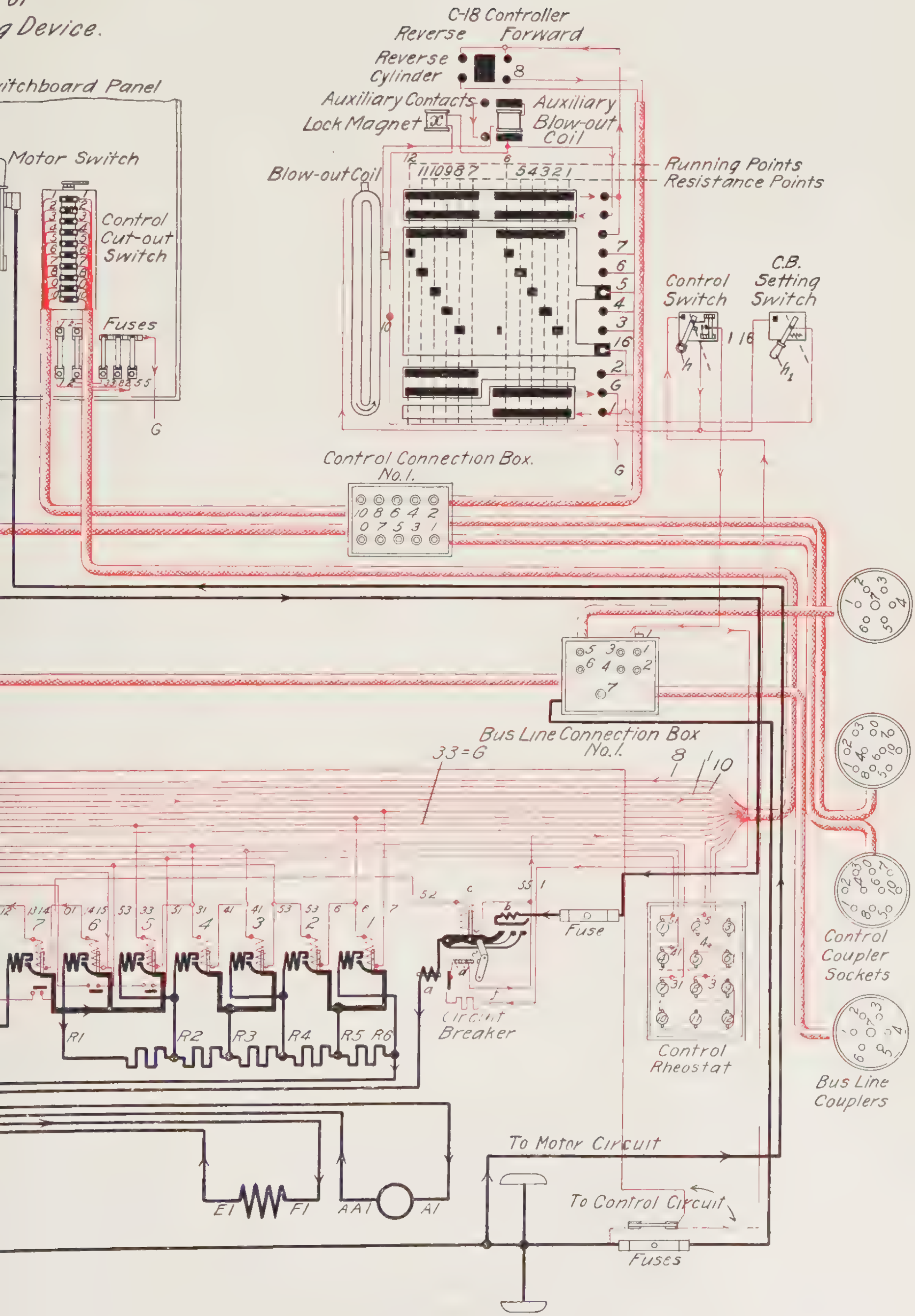
WIRING DIAGRAM OF TYPE M CONTROL WITH CURRENT-LIMITING DEVICE

29. General Description.—Fig. 20 is a diagram of connections for type M control with C18 controllers. The chief differences between this diagram and that shown in Fig. 18 lie in the number and arrangement of the contactors and the addition of an automatic device that prevents the car from taking more than a predetermined current at starting. The contactors are of the type already described, those of approximately the same potential being grouped together on a common base, to economize space and simplify connections. In order to insure the fastest possible acceleration without slipping of the wheels, the following arrangement is provided: The controller cylinder instead of being positively driven by the shaft to which the operating handle is attached, is connected thereto by means of a spring; a magnetically operated lock prevents the cylinder from following the movement of the operating handle so long as the current taken by the motors exceeds the allowable amount. Thus, if the motorman were to throw the operating handle around rapidly to, say, the full series position before the motors had time to gain headway, the train would take an excessive current if no automatic throttle or current-limiting device were provided, and wheel slippage would occur. In this controller, the power drum does not at once follow the movements of the handle; a rapid movement of the handle simply places the spring between the handle and shaft under tension, and the latter cannot move until it is unlocked. When the current falls to an amount sufficient to unlock the shaft, the spring moves the cylinder forwards, with the result that it follows the movement of the handle step by step until it reaches the position occupied by the handle. If the motorman moved the power handle so slowly that the starting current never exceeded the allowable amount, the drum would not be locked and it would follow the movements of the handle as in an ordinary controller. In practice, however, where this type of controller is used, the motorman

Car Wiring for Spr
Type
With Current



General Electric
rol
g Device.



throws the handle around to the running position and the controller notches up as fast as the locking device will permit.

30. In Fig. 20, the locking device is controlled by the electromagnet x on the master controller and the current in this magnet is controlled by the relay shown at y. The relay consists of a coil connected in series with one of the motors so that it carries the main current. If the current exceeds the allowable amount, the relay operates and connects magnet x in shunt with one or the other of the reverser operating coils, according to which is in use, thus locking the controller. When the current drops below the limit, the current through y decreases until the relay contacts are opened and the magnet in the controller unlocks the cylinder and allows it to move under the influence of the spring connected to the main shaft.

It will not be necessary to trace out the paths of the current on all the notches in Fig. 20, since this can be done from the explanation given in connection with Fig. 18. The contactors are arranged differently and their sequence of operation differs from that in Fig. 18, but the principle of operation is the same. On the first position of the master controller, the control-current path is indicated by the red arrowheads and the main-current path by the black arrowheads. The two bus-line connection boxes, the cable connecting them, and the extra pairs of couplers on each end of the car, have to do with an extra train line provided for several purposes. One object is to enable any current-operated device to get its current either from the car on which it is located or from some other car in the train. To illustrate: when either control-switch handle h is thrown to the dotted position, the dependent master controller can take current either from the trolley direct or from the bus-line connection-box trolley terminal 7, which is connected to the contact shoes of all cars. This is an important feature, because where a master controller can draw current only from the contact shoes of the car on which it is located, should those shoes happen to rest on ice or be off the rail entirely,

it would be necessary to go to another car in order to start the train.

31. Another feature of this control is the automatic main-current circuit-breaker and the facilities for setting it before starting or resetting it after operation. The breaker is located to the right of the contactors in Fig. 20. Here *a* is the operating coil and *b* the blow-out coil; both carry the main current, the circuit-breaker being the first device through which the main current passes after leaving the motor switch. By means of setting coil *c*, the circuit-breaker can be set by moving handle h_1 of either circuit-breaker setting switch to the dotted position. The circuit-breaker can be closed by operation of the setting switch only when the accompanying master controller is at off-position, because in all other positions fingers *5* and *16*, which are part of the setting circuit, make no contact. When switch h_1 is closed, the path of the current through setting coil *c* is as follows, starting from point *16* at setting switch: *16*–setting switch finger *16* on controller–finger *5*–cut-out switch–*5* on control rheostat–*2*–*1*–*51*–*51*–interlock on contactor *10*–interlock on contactor *8*–interlock on contactor *7*–*52*–setting coil *c*–*55*–*55*–fuse–ground. If contactors 7, *8*, or *10* are closed, the circuit-breaker cannot be set, and it is therefore impossible to set, the breaker while the main-motor current is on. Setting coil *c* moves the circuit-breaker parts over to where armature *e* on the togglejoint comes within the range of holding coil *d*, which is steadily energized from the bus-line connection box through resistance *f*. Coil *d* holds the breaker closed after the circuit-breaker setting switch has been moved to off-position or after the master controller has been moved to an operating position. As long as the circuit that energizes holding-magnet *d* is closed, the circuit-breaker will remain closed. Excessive current in the motor circuit, however, will cause operating coil *a* to attract its armature composing part of the holding-coil circuit, which is thereby opened and the breaker thrown into operation.

32. Table II shows the contactors in operation on the positions of the C18 controller. The plan of wiring shown in Fig. 18 is the one generally used for ordinary multiple-unit equipments; the arrangement in Fig. 20, which is somewhat more complicated and which includes the auxiliary features just explained, is used in places where the traffic is heavy and where the requirements are unusually exacting, as, for example, in the New York subway.

TABLE II

Positions	Contactors in Action															
1						6	7		9						15	
2					5	6	7		9	10					15	
3				4	5	6	7		9	10	11				15	
4			3	4	5	6	7		9	10	11	12			15	
5		2	3	4	5	6	7		9	10	11	12	13		15	
6	1	2	3	4	5	6	7		9	10	11	12	13	14	15	
7						6	7	8	9							16
8					5	6	7	8	9	10						16
9				4	5	6	7	8	9	10	11					16
10			3	4	5	6	7	8	9	10	11	12				16
11		2	3	4	5	6	7	8	9	10	11	12	13			16
12	1	2	3	4	5	6	7	8	9	10	11	12	13	14		16

AUTOMATIC RELAY CONTROL

DESCRIPTION OF APPARATUS

33. Controller.—A later system, embodying the general features of the type M control and known as the **automatic relay control**, has been developed by the General Electric Company. Fig. 21 shows the C35 controller used in this system of control. This controller contains a single movable contact cylinder and ten stationary fingers.

The controller has a single handle for both forward and reverse directions of train movement. There are four forward points and two reverse points. The first point in either direction is the *switching*, or *lap*, *position;* the second point, *full-series position;* the third point forward, the *parallel-lap position;* and the fourth point forward, the *full-parallel position*.

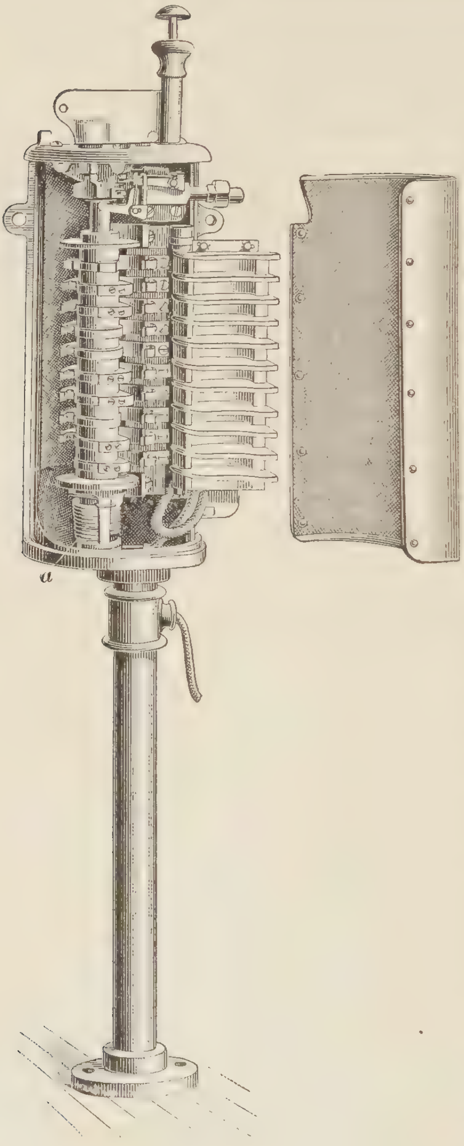


FIG. 21

If it is desired to have the control notch up to the maximum forward-speed position, the operating handle should be moved to the left as far as it will go, and held there against the pressure of the spring *a*, which tends to return the handle to the off-position. The contactors pick up in proper sequence, cutting out the resistance sections and changing the motors from series connection to full-parallel connection. If the

controller handle is moved toward the right to the second reverse point, the motors will notch up to full-series position only, and the train speed will be about half that at the forward full-parallel position.

34. Current-Limit Relay.—The **current-limit relay,** which is mounted on the panel board, is provided

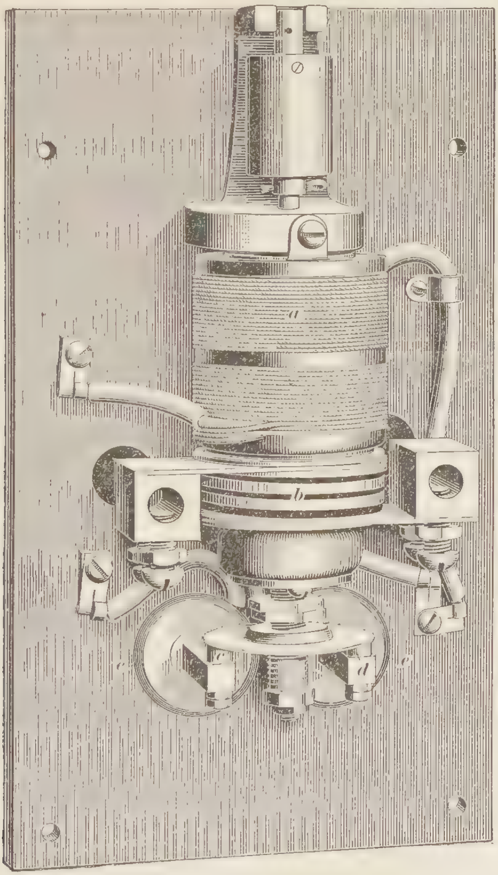


Fig. 22

for the purpose of producing automatic operation of the control system. Fig. 22 shows the main features of this device.

Current from the control circuit passes through the coil *a*, and current from one motor circuit passes through coil *b*. Coil *a* lifts the plunger and its disk at each step during acceleration, and thus interrupts the contactor pick-up circuit at the contacts *c* and *d*. Blow-out coils *e* extinguish any arcs that may form between the contacts and the disk. If the current flowing through the main-circuit coil *b* is more than a predetermined amount, the plunger and its disk are held in their upper position, and cannot drop to their lower positions until the motor current has fallen to the desired value. The action of the contactors in cutting out resistance is thus delayed until normal current conditions again obtain.

35. Potential Relay.—Fig. 23 shows a **potential relay**. This device is used to open the control circuit of the contactors on a car in case the motor circuit on that car is interrupted; the contactors will thus drop out. When current is restored to the car, the relay will again pick up and complete the control circuit. The contactors will then pick up in regular succession, as they would if the motorman had shut off the power and immediately turned the master-controller handle on again. Coil *a* is connected between a point on the motor circuit, ahead of the motor, and the ground. When the motor circuit is active, disk *b* is drawn into contact with *c* and *d*, which are terminals of blow-out coils *e*, *e* connected in the control circuit. If current through coil *a* ceases, disk *b* drops and opens the control circuit of the contactors. This relay is mounted in the contactor box.

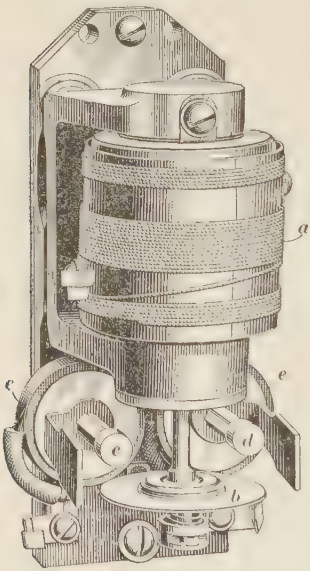


Fig. 23

36. Circuit-Breaker.—In Fig. 24 is shown a **circuit-breaker** used to interrupt the motor circuit in case of excessive current. The circuit-breaker is quite similar in construction to a contactor switch. The blow-out coil *a* is in the motor circuit, and disrupts any arc that may form when the breaker is opened. The resetting coil *b* is in the control circuit. The tripping device is provided with a coil *c*; this coil is in the control circuit and will open the breaker in case current from the control circuit is allowed to flow through it. Another tripping coil placed to the right of *c* (not shown in

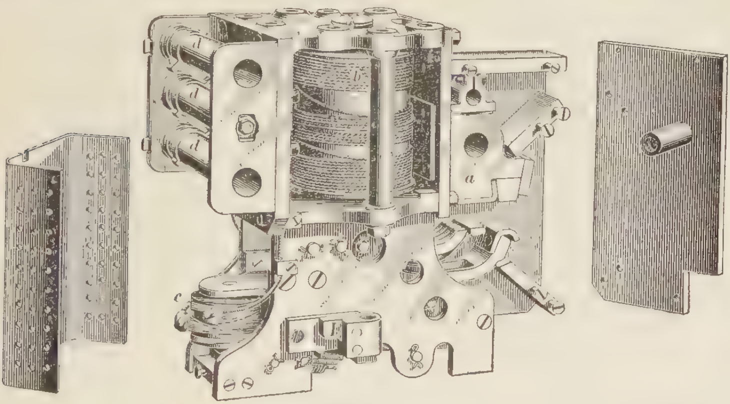


FIG. 24

the figure) is also provided. This latter coil is in series with the motor circuit, and will open the breaker if the motor current becomes excessive.

A three-point switch for tripping or setting the breaker is installed near the motorman. The resetting coil *b* is so connected with two of the contactor interlocks—one or both of which are open during motor action due to one or both of the contactors being closed—that the breaker cannot be set while there is current in the motor circuit. The three resistance coils *d* are in circuit with the control-tripping coil.

37. Cut-Out Switch.—Fig. 25 shows a **cut-out switch.** When the switch drum is turned to the on-position, each finger on one side is connected to the finger directly

opposite it. When at off-position, there is no connection between the fingers. Fuses are installed in the clips at the right of the drum. In case of disorder in the apparatus or

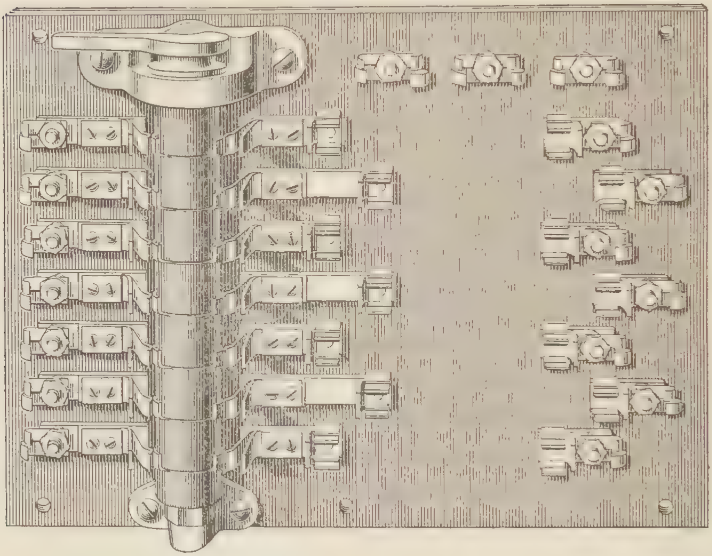
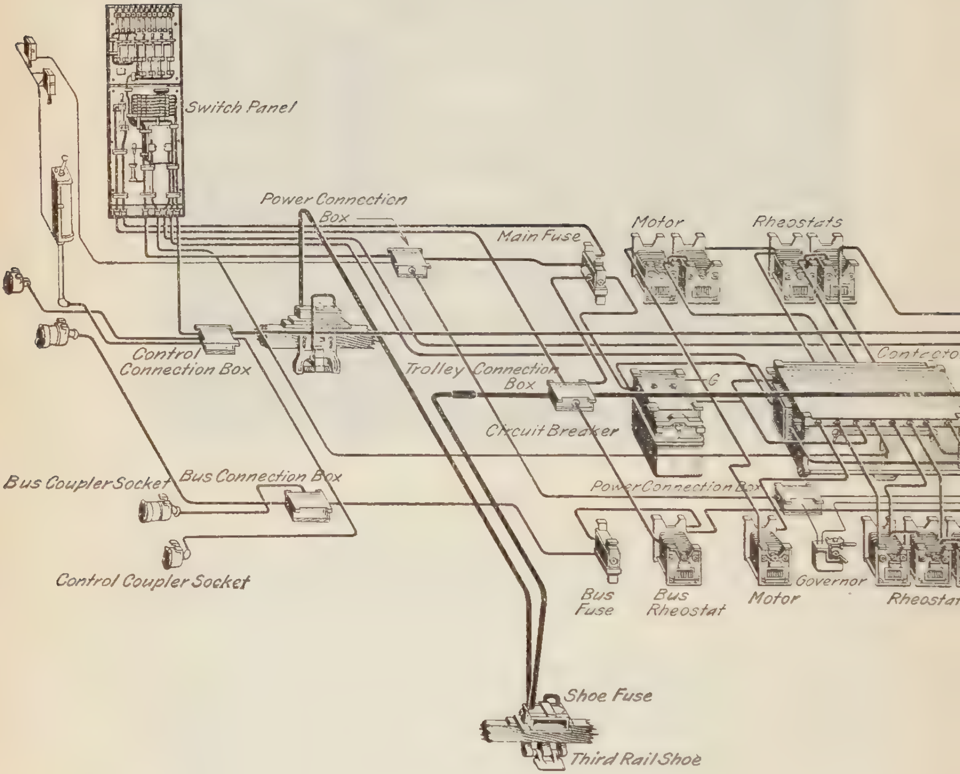


FIG. 25

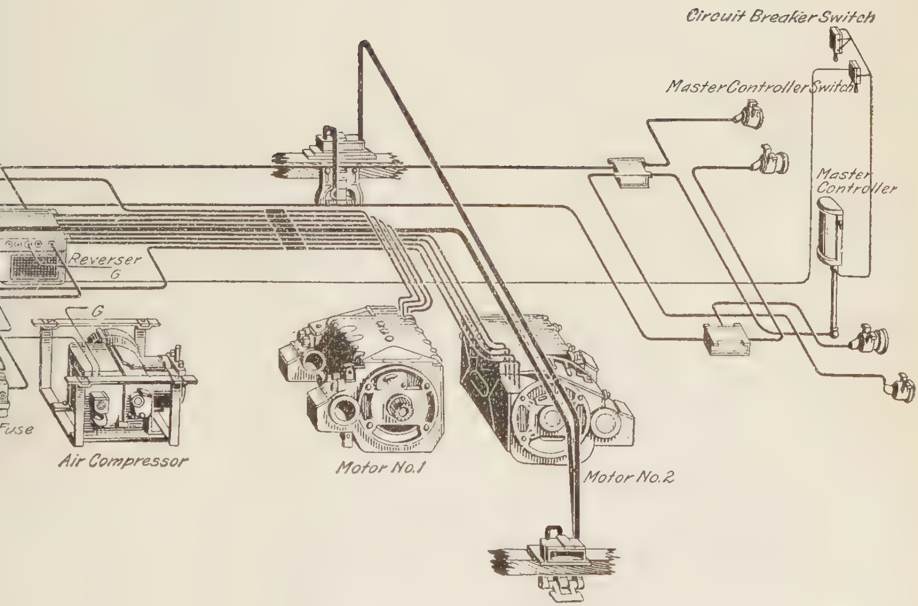
wiring of a car, the control circuits of the contactors and reverser on that car may be disconnected from the train cable by the action of the cut-out switch.

38. **Train Cable.**—The **train cable** is composed of seven conductors, each being covered with different colored braiding for identification. These conductors are attached to numbered plugs in the coupler sockets at the ends of the car, and branch wires extend to the master controllers.

These seven wires are used as follows: No. 1, for accelerating, or notching up; No. 2, for series connection of motors; No. 3, for parallel connection of motors; No. 4, for operating the reserver in one direction; No. 5, for operating the reserver in another direction; No. 6, for tripping the circuit-breaker; No. 7, for setting the circuit-breaker.



Switch Panel
Power Connection Box
Main Fuse
Motor
Rheostats
Contactor
Control Connection Box
Trolley Connection Box
G
Circuit Breaker
Power Connection Box
Bus Coupler Socket
Bus Connection Box
Control Coupler Socket
Bus Fuse
Bus Rheostat
Motor
Governor
Shoe Fuse
Third Rail Shoe

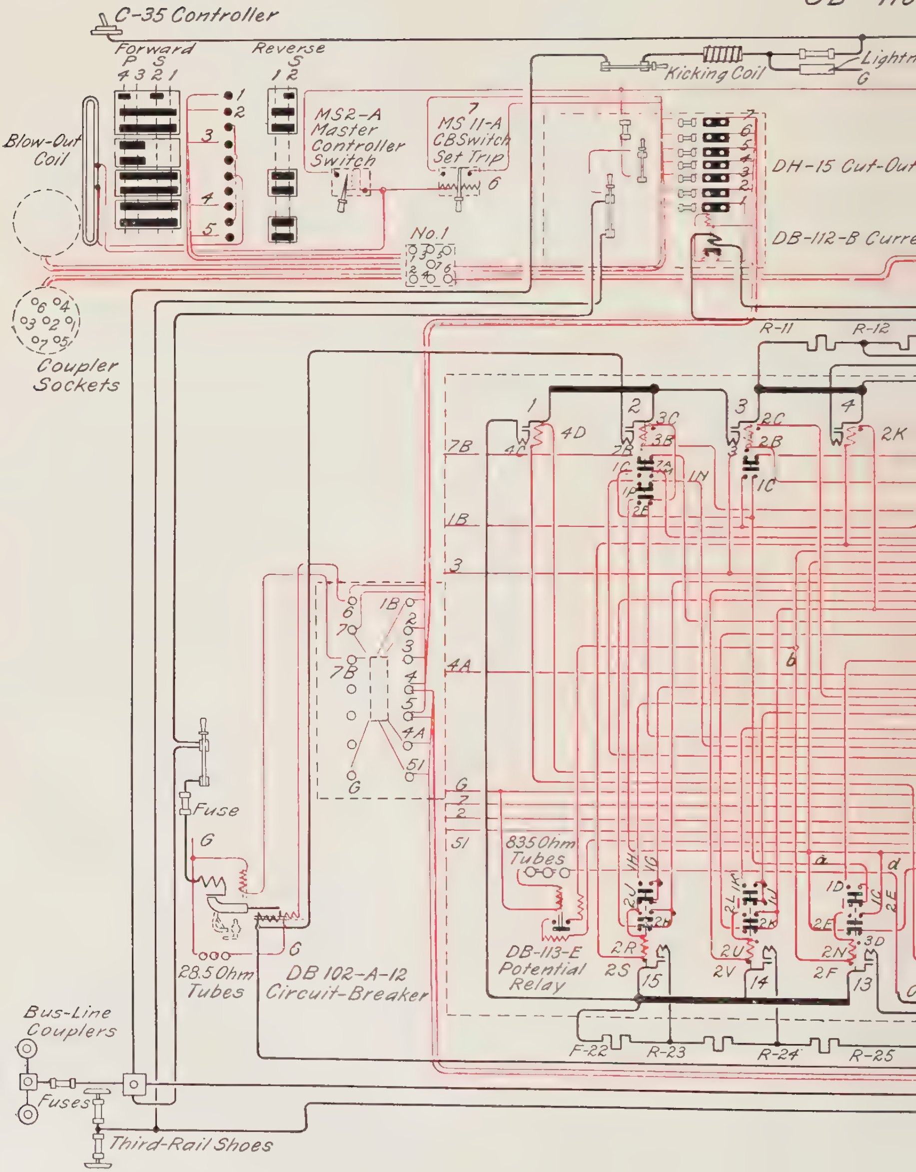


Circuit Breaker Switch
Master Controller Switch
Master Controller
Reverser
G
G
Fuse
Air Compressor
Motor No.1
Motor No.2

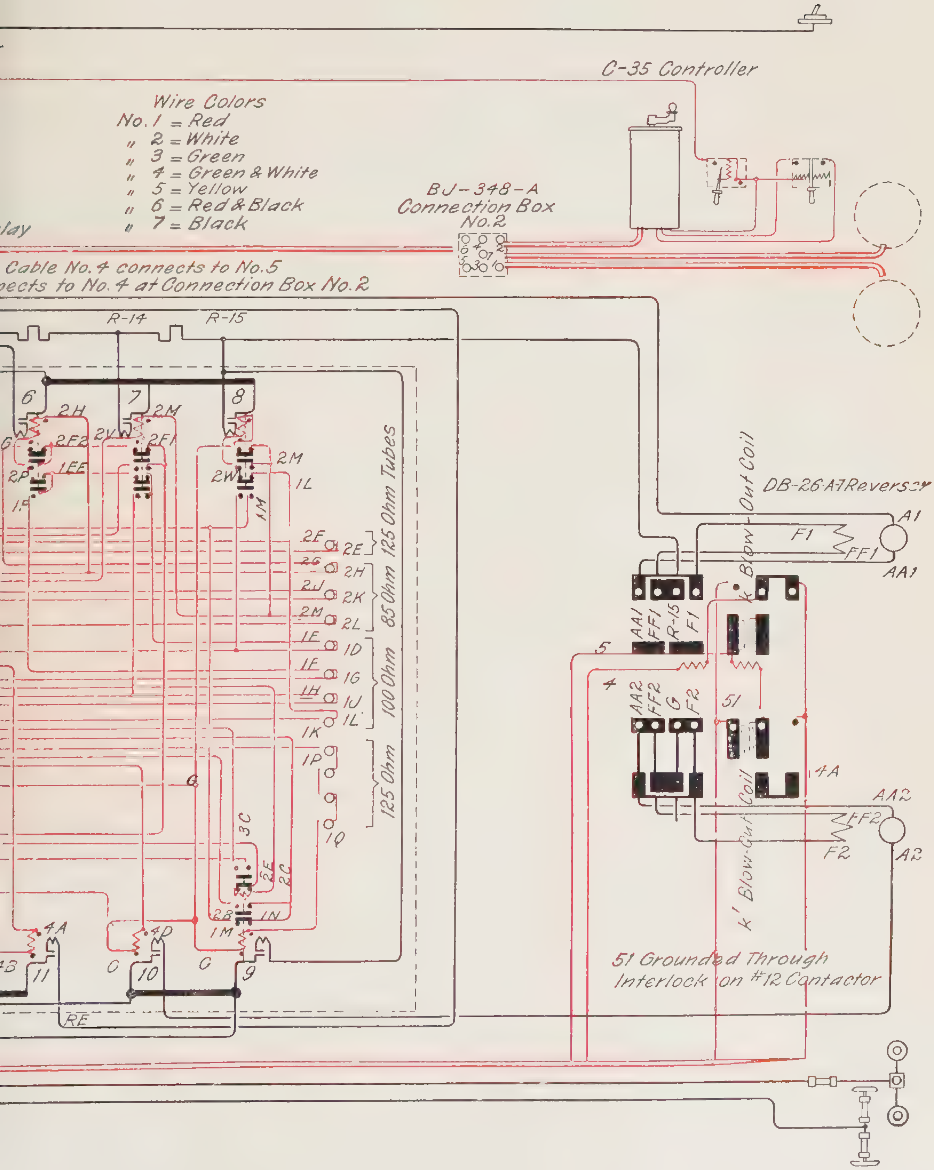
Car Wiring for ...

Type M A...

SB - 416...



ue-General Electric
ic Relay Control
ntactor Box



6 42 26874

39. Arrangement of Apparatus on a Car.—In Fig. 26 is shown the general arrangement of apparatus on a car of the New York Central & Hudson River Railroad Company.

WIRING DIAGRAM OF THE AUTOMATIC RELAY CONTROL

40. General Description.—In Fig. 27 is shown a car-wiring diagram of the automatic relay control with C35 controllers. Before starting a train, the motorman should close the motor switches for the air compressors, and then make a test to assure himself that the braking apparatus is in proper condition. The main switches on all cars should be closed and all master-controller switches, with the exception of the one near the controller that is to be operated, should be left open.

If it is desired to have the control automatically notch up to the maximum-speed position, the operating handle should be moved at once to the forward full-parallel position.

Current flows through the master-controller switch–blow-out coil–the four forward lower drum segments–wire *4*–left-hand operating coil in the reverser–through blow-out coil *k–51–51* in the contactor connection box–wire *51* in the contactor box–*51*–interlock on contactor *12* (contactor *12* open) to ground, if the reverser is at reverse position; if at the forward position, through reverser control segments–*4A–4A* in the contactor connection box–wire *4A*–in the contactor box –*4A*–operating coil of contactor *11–4B*–operating coil of contactor *12–4C–4C*–operating coil of contactor *1–4D–4D*–operating coil of contactor *10*–ground wire. Operating coil *4* of the reverser pulls the reverser to forward position, if it was formerly in the reverse position, or maintains it at forward position in case it was originally in that position. The current through the rest of the path just traced closes contactors *11*, *12*, *1*, and *10*.

Current passes also from the master controller through train wire *2* (called the *retaining wire*)–interlock of contactor *12* (which is now closed as the contactor is closed)–*2A–2A*–interlock of contactor *5*–junction *c–2B*–operating coil of

contactor *3*–*2C*–*2C*–interlock of contactor *9*–*2E*–junction *a*–*2E*–resistance–*2F*–junction *b*–potential relay (which is now closed)–*2F1*–interlock of contactor *7*–*2F2*–interlock of contactor *6*–*2G*–*2G*–resistance–*2H*–*2H*–interlock of contactor

FIG. 28

15–*2J*–*2J*–resistance–*2K*–*2K*–interlock of contactor *14*–*2L*–*2L*–resistance–*2M*–*2M*–interlock of contactor *8*–ground wire.

Contactor *3* is closed, and as contactors *11*, *12*, *1*, and *10* were previously closed, the motors are now connected in

series with all the resistance in circuit, as indicated in Fig. 28, at the first step, or switching position. The closed switches are indicated by small, full-black circles. If it is desired to operate the train at low speed, as for switching, the handle should be left on the first point.

41. In the case under consideration, full speed is desired; therefore, controller finger *1*, Fig. 27, is active, as the handle has been moved to the full-parallel position. The No. *1* wire, or the *notching wire*, as it is called, is energized, and the circuit is established through the current-limit relay and the resistance contactors, so that progressive steps are started. In picking up, each of these resistance contactors prepares the control circuit, by means of interlocking switches located on the bottom of the contactors, for the next step. The interlocks are called first, second, third, and fourth, beginning with the interlock shown nearest the operating coil of the contactor. The contactors, in turn, are cut out of the notching circuit and connected in the retaining circuit.

The current-limit relay lifts at each step, thereby preventing the contactor for the succeeding step from lifting at once. If the motor-circuit current is excessive, the relay is held open until the current becomes normal and the progression of steps is temporarily arrested. When the relay finally drops, due to the motor current becoming normal and to the open circuit in the control circuit, the control circuit is again completed and another contactor is operated. This action, which is entirely automatic, is repeated until the last, or full-parallel, position of the contactor is reached.

42. The path of the current in the notching circuit is from controller finger *1*–current-limit relay–*1B*–*1B*–interlock of contactor *3* (contactor *3* closed)–*1C*–*1C*–interlock of contactor *13* (contactor *13* open)–*2N*–operating coil of contactor *13*–*2F*–junction *b*–ground through potential relay by the path traced for the wire *2*. This action closes contactor *13* and cuts out three sections of resistance. See Fig. 28.

43. Current from the retaining circuit, Fig. 27, can now flow through *2E* near the interlock of contactor *9*–junction *d*–*2E*–interlock of contactor *13* (contactor *13* now closed)–*2N*–operating coil of contactor *13*–*2F*–junction *b*–ground, as before. Contactor *13* is thus maintained closed. The notching circuit through the operating coil of contactor *13* was broken when the contactor closed, thus opening its third interlock. As soon as the current-limit relay again closes the notching circuit, current flows from *1C*–fourth interlock of contactor *13* (contactor *13* now closed)–*1D*–*1D*–resistance–*1E*–interlock of contactor *7*–*1EE*–interlock of contactor *6*–*2P*–operating coil of contactor *6*–*2H*–*2H*–interlock of contactor *15*–*2J*–*2J*–resistance–*2K*–*2K*–interlock of contactor *14*–*2L*–*2L*–resistance–*2M*–*2M*–interlock of contactor *8*–ground. Contactor *6* closes and cuts out one section of resistance. See Fig. 28.

44. The retaining circuit, Fig. 27, is closed through the operating coil of contactor *13* (contactor closed)–*2F*–junction *b*–potential relay–*2F1*–interlock of contactor *7*–*2F2*–interlock of contactor *6* (contactor *6* closed)–*2P*–operating coil of contactor *6*–*2H*–ground, as before.

From point *1EE* current from the notching circuit flows from *1EE*–interlock of contactor *6* (contactor *6* now closed)–*1F*–*1F*–*1G*–*1G*–interlock of contactor *15*–*2R*–operating coil of contactor *15*–*2S*–operating coil of contactor *4*–*2K*–*2K*–interlock of contactor *14*–*2L*–*2L*–resistance–*2M*–*2M*–interlock of contactor *8*–ground.

Contactors *15* and *4* are closed. Contactor *4* cuts out one more section of resistance. The resistance controlled by contactor *15* is already short-circuited by contactor *13*, but in parallel operation, contactors *13*, *14*, and *15* are independently active.

The retaining circuit is made through *2H*–interlock of contactor *15* (contactor *15* closed)–*2R*–operating coil of contactor *15*–*2S*–operating coil of contactor *4*–*2K*–*2K*–interlock of contactor *14*–ground, as before.

45. Current from the notching circuit can now flow from *1G*–interlock of contactor *15* (contactor *15* now closed)–

1H–1H–resistance–*1J–1J*–interlock of contactor *14–2U*–operating coil of contactor *14–2V–2V*–operating coil of contactor *7–2M–2M*–interlock of contactor *8*–ground.

Contactors *14* and *7* are closed. Contactor *7* cuts out a section of the resistance. The resistance controlled by contactor *14* is already cut out.

The retaining circuit is made through *2F1*–second interlock of contactor *7* (contactor *7* closed)–operating coil of contactor *4–2K*–interlock of contactor *14* (contactor *14* closed)–*2U*–operating coil of contactor *14–2V–2V*–operating coil of contactor *7–2M*–ground, as before.

The operating coils of contactors *6* and *15* are dropped out of the retaining circuit by the open circuit at the upper interlock of contactor *7*. Contactors *6* and *15* then open. The resistances they control are now short-circuited by contactors *7* and *14*.

46. Current from the notching circuit now flows from fourth interlock of contactor *7* (contactor *7* closed)–*1H*–resistance–*1J–1J*–interlock of contactor *14* (contactor *14* closed)–*1K–1K*–resistance–*1L–1L*–interlock of contactor *8* (contactor *8* open)–*2W*–operating coil of contactor *8*–ground.

Contactor *8* closes and cuts out the last section of the upper resistance. The retaining circuit is made through *2M*–interlock of contactor *8* (contactor *8* closed)–*2W*–operating coil of contactor *8*–ground.

47. The fourth interlock of contactor *8* is now closed (contactor *8* being closed), and the notching circuit is completed through *1D* near the interlock of contactor *13* (contactor *13* closed)–fourth interlock of contactor *8* (contactor *8* closed)–*1M–1M*–interlock of contactor *9–1N–1N*–interlock of contactor *2–1P–1P*–resistances–*1Q*–operating coil of contactor *9*–ground.

Contactor *9* closes, and current from the retaining circuit now flows from junction *c–2B*–interlock of contactor *9–1N–1N*–interlock of contactor *2–1P–1P*–resistances–*1Q*–operating coil of contactor *9*–ground.

48. The third interlock of contactor *9* is now open, due to the closing of contactor *9*. A portion of the retaining circuit is opened by this interlock between *2C* and *2E*. Current cannot now flow from junction *c* through the operating coils of contactors *3*, *13*, *4*, *14*, *7*, and *8*; therefore, these contactors drop open.

The motors are now in series without resistance sections in circuit, as indicated by full-series position in Fig. 28. The negative side of motor No. *1*, Fig. 27, is connected by contactor *9* to the positive side of motor No. *2*.

49. The fourth interlock of contactor *9* closes the No. *3* wire circuit. Current flows from controller-drum finger *3*–wire *3*–*3*–interlock of contactor *3* (contactor *3* open)–*3A*–operating coil of contactor *5*–*3B*–*3B*–operating coil of contactor *2*–*3C*–*3C*–interlock of contactor *9* (contactor *9* closed)–*3D*–interlock of contactor *13* (contactor *13* open)–*2E*–*2E*–resistance–*2F*–junction *b*–potential relay–*2F1*–interlock of contactor *7* (contactor *7* open)–*2 F2*–interlock of contactor *6* (contactor *6* open)–*2G*–*2G*–resistance–*2H*–*2H*–interlock of contactor *15* (contactor *15* open)–*2J*–*2J*–resistance–*2K*–*2K*–interlock of contactor *14* (contactor *14* open)–*2L*–*2L*–resistance–*2M*–*2M*–interlock of contactor *8* (contactor *8* open)–ground.

Contactors *5* and *2* close. Contactor *5* furnishes a ground connection for the No. *1* motor. Contactor *2* furnishes a trolley connection for the No. *2* motor through contactors *1* and *10*, which remain closed. The retaining circuit of the operating coil of contactor *9* is opened between *1N* and *1P* at the third interlock of contactor *2* when contactor *2* closes, and between *2A* (near contactor *5*) and junction *c* at the second interlock of contactor *5* when contactor *5* closes. Contactor *9* thus opens and cuts out the connection between the two motor terminals, and in this manner separates the motors.

The retaining circuit is now completed through wire *2*–*2*–interlock of contactor *12* (contactor *12* closed)–*2A*–*2A*–fourth interlock of contactor *5* (contactor *5* closed)–*3*–interlock of

contactor *3* (contactor *3* open)–*3A*–operating coil of contactor *5*–*3B*–*3B*–operating coil of contactor *2*–*3C*–fourth interlock of contactor *2* (contactor *2* closed)–*2E*–junction *a*–*2E*–resistance–*2F*–junction *b*–potential relay–*2F1*, etc. –ground.

50. The notching circuit is now completed through wire *1B*–interlock of contactor *5*–*1D*–*1D*–resistence–*1E*–third interlock of contactor *7*–operating coil of contactor *6*, etc. –ground. Contactor *6* closes, thus cutting out a section of resistance.

The retaining circuit is made through wire *2*–*2*–interlock of contactor *12*–fourth interlock of contactor *5*–interlock of contactor *3*–operating coil of contactor *5*–operating coil of contactor *2*–interlock of contactor *2*–*2E*–junction *a*–*2E*–resistance–*2F*–junction *b*–potential relay–*2F1*–interlock of contactor *7*–*2F2*–*2P*–operating coil of contactor *6*–*2H*–*2H*–interlock of contactor *15*–*2J*–*2J*–resistance–*2K*–interlock of contactor *14*–*2L*–*2L*–resistance–*2M*–interlock of contactor *8*–ground.

The connections at this point are shown in Fig. 28—parallel-lap position. The motors are in parallel with three resistance sections in series with each motor.

51. The current from the notching circuit now flows through *1EF*–fourth interlock of contactor *6*–*1F*–resistance –*1G*–operating coil of contactor *15*–operating coil of contactor *4*–interlock of contactor *14*–*2L*, etc.–ground. Each contactor *15* and *4* in closing cuts out a resistance section.

The retaining circuit is made through *2H*–operating coil of contactor *15*–operating coil of contactor *4*, etc.–ground.

52. The current from the notching circuit now flows through *1G*–interlock of contactor *15*–*1H*–resistance–*1J*–operating coil of contactor *14*–operating coil of contactor *7*, etc.–ground. Contactors *14* and *7* close, and each cuts out a section of resistance.

The retaining circuit is now completed through *2F1*–second interlock of contactor *7*–operating coil of contactor *4* –operating coil of contactor *14*–operating coil contactor *7*,

etc.–ground. Contactors *6* and *15* are opened by the action of the first interlock of contactor *7*, which opens the retaining circuit through the operating coils of contactors *6* and *15* when contactor 7 is closed.

53. The current from the notching circuit now flows from the fourth interlock of contactor *7–1H*–resistance–*1J–1J–1K–1K*–resistance–*1L*–interlock of contactor *8*–operating coil of contactor *8*–ground. Contactor *8* closes and cuts out the last section of resistance in No. *1* motor circuit.

The retaining circuit is made through *2 M*–interlock of contactor *8*–operating coil of contactor *8*–ground.

54. The current from the notching circuit now flows from wire *1B*–interlock of contactor *5–1D*–fourth interlock of contactor *8–1M–1M*–interlock of contactor *2–1C–1C*–operating coil of contactor *13–b*–potential relay–ground. Contactor *13* in closing cuts out the last resistance section in the No. *2* motor circuit.

The retaining circuit is completed through the fourth interlock of contactor *2–2E*–junction *d–2E*–operating coil of contactor *13*–junction *b*–potential relay–operating coils of contactors *4*, *14*, *7*, and *8*–ground. The motors are now in full-parallel connection, as indicated in Fig. 28.

55. When the controller handle is thrown to the No. *2* point in the reverse direction, Fig. 27, finger *5* is energized and the reverser is thrown to the reverse position, thus interchanging the field terminals. On the reverse position, wire *5* is connected to wire *4A* in the reverser. The contactors and their interlocks notch up to full-series position. As the motors do not enter into parallel connection for the reverse positions of the controller handle, the speed will be only about half forward maximum speed. The first point is the reverse switching position, and the second point the reverse full-series position.

56. **Operating Instructions.**—If it is desired to operate the train at low speed, as in switching, the master-controller handle should be moved to the left, for forward

direction, or to the right for reverse direction, to the first point only. On this point, the full resistance will be in circuit, with the two motors in series, and the control will not notch up. If it is necessary to increase the speed slightly, the controller handle should be moved to the second point, so as to start the automatic progression of the contactors through the resistance steps, and then quickly returned to the first, or lap, position. The notching up will be arrested, but the contactors that have picked up and cut out more resistance will remain closed. This manipulation of the controller handle may be repeated, and a slow acceleration obtained when it is necessary. If the handle is left on the second point for a sufficient length of time, all of the resistance will be automatically cut out of the motor in successive steps under the control of the current-limit relay, until full-series position of the motors is reached, resulting in half speed.

57. When it is necessary to reverse the direction of train movement, the master-controller handle should be turned to the right. The first point in this direction is a switching point, similar to first point forward, and when the handle is on this point, the train will move slowly without materially increasing its speed. If a higher speed is desired, the handle should be moved to the second point, and the automatic notching for cutting out the resistance and obtaining half speed in the reverse direction should be started. The second point leaves the motors in series relation.

58. Returning the master-controller handle to the off-position cuts off the supply of current to the train cable and contactors, and the latter therefore drop out and open the main circuit through the motors. Should the motorman remove his hand from the controller handle while it is at an on-position, a spring will return the handle to the off-position and thereby automatically cut off power from the train.

59. The controlling cut-out switch disconnects the operating parts of contactors and reverser on the car from the train cable, but does not affect the operation of the rest of

the train, although the car may be the one from which the train is being operated.

60. The arrangement of apparatus is such that the train may be operated in either direction from any master controller in the train. In order to operate in a reverse direction at full speed, however, it is necessary to operate from a master controller at the end of a car toward the direction in which the train is to be moved.

61. Should the train break apart, the control couplers will pull out, cutting off current from the train cable on the section of train behind the break. This drops out all the contactors on the rear section, while the front section continues under the control of the motorman.

62. The control connections for the reverser are so arranged that, unless it is at the proper position, current is cut off from the contactors, and, consequently, the motors on that car receive no current. When the reverser is in the correct position, it is electrically locked and cannot be operated while the motors are taking current.

63. All the wires of the master-control circuit are protected by means of small fuses from damage due to excess current. In case of electrical trouble within the master-controller train cable, couplers, or connection boxes, the single fuse in the master-controller switch will protect them. In case of trouble in the control circuit at contactors or reverser, the fuses on the panel board situated in or near the motorman's apartment will protect the circuit.

MULTIPLE-UNIT SYSTEMS

(PART 2)

WESTINGHOUSE UNIT-SWITCH CONTROL

GENERAL DESCRIPTION

1. The **Westinghouse unit-switch system** of train control differs considerably from the type M system already described, but the difference is more in the details of appliances than in the results obtained by their operation. Excepting the master controller, all circuit-making and circuit-breaking devices of the unit-switch equipment are operated by compressed air controlled by electrically operated valves, of which the time and order of operations depend on circuit combinations established by the master controller. The main controller consists of thirteen individual *unit switches* grouped radially. The train line consists of seven wires terminating in sockets, and the circuits of these wires are continued from car to car by flexible jumpers.

The train line and all operating devices dependent on it are energized through the master controller by a storage-battery current supplied at a pressure of about 15 volts. The battery consists of fourteen cells arranged in two sets, having seven cells, in series, in each set. When one set is in service, the other is being charged through the car-lamp circuit, double-throw switches being provided to make the

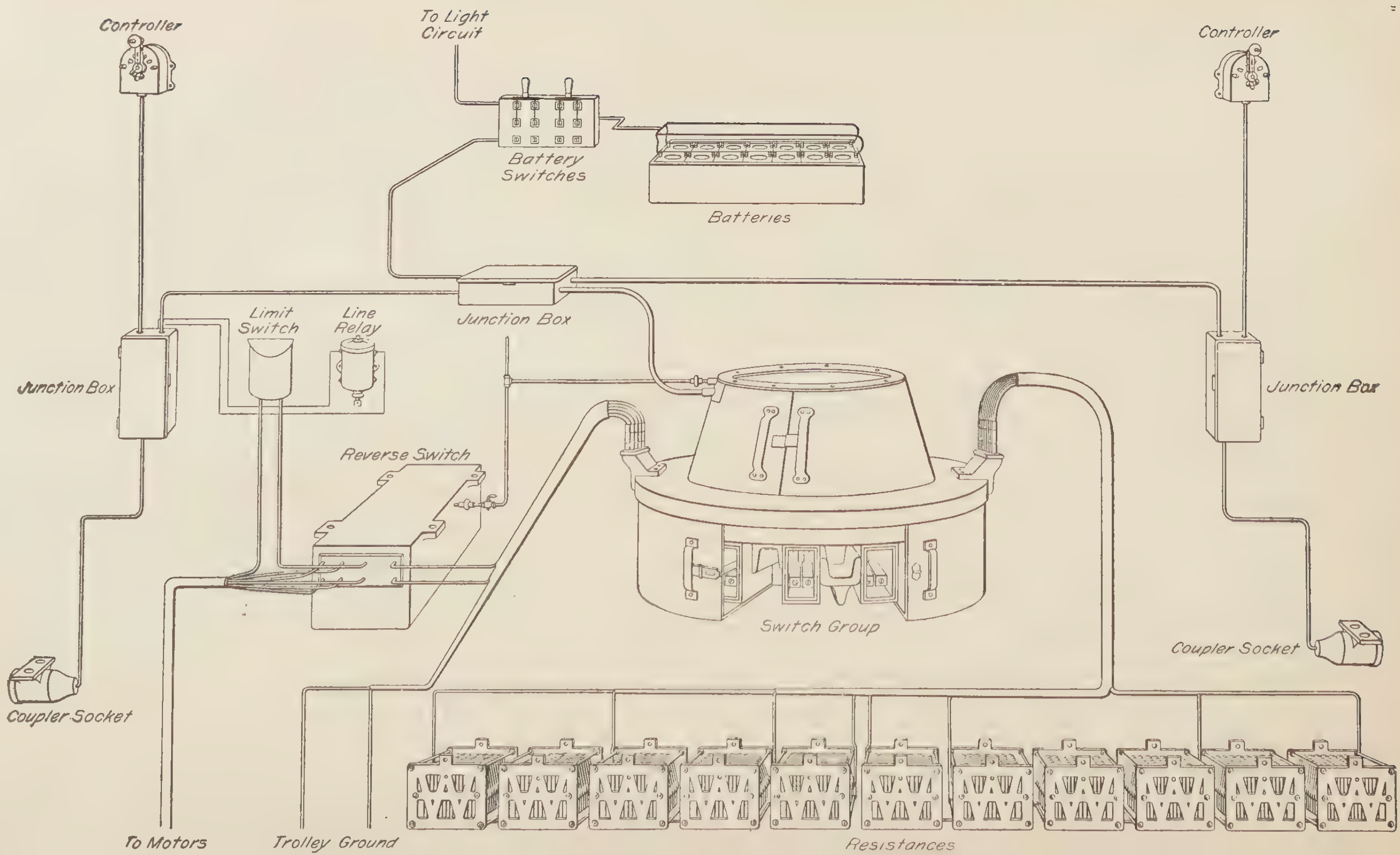

Controller
To Light Circuit
Battery Switches
Batteries
Controller
Junction Box
Limit Switch
Line Relay
Junction Box
Junction Box
Reverse Switch
Switch Group
Coupler Socket
Coupler Socket
To Motors
Trolley Ground
Resistances

FIG. 1

necessary changes for charging and discharging. The use of an independent source of operating current renders operation of the control circuit practicable under conditions of service, such as a film of ice on the trolley wire or contact rail or in case the power goes off the line; it is also probable that the control circuits are not nearly so likely to become disordered by lightning discharges. The low voltage used in the control circuits considerably simplifies the problem of insulating the control wires and securing durable coupling devices.

2. A unit-switch control equipment comprises the following devices: Unit-switch group, master controllers, motor cut-out switches, resistances, storage battery, reverse switch, train line, limit and line relay switches, air connections, and line switches, if required. In considering any device, an understanding of it will, in each case, be made easier by locating the device in Fig. 17, in which the connections are indicated. Fig. 1 shows an assembly of the unit-switch equipment.

CONTROL DEVICES

UNIT, OR AIR, SWITCHES

3. Fig. 2 shows the location under a car of the **unit-switch group** constituting the main controller. Fig. 3 shows the device with the housing removed, and Fig. 4 is a section through the center of the group shown in Fig. 3; from this drawing the construction of a unit switch and the mechanism for operating it can be understood. The controller consists of thirteen switches *a*, *a*, Figs. 3 and 4, arranged radially around a blow-out coil *b* that is common to all. (One of the unit switches is shown more in detail at the left of Fig. 4.) The fixed contact of the switch is shown at a'; the movable one at b' is on the end of arm *c*, which has a slight movement around pin *d*. Arm *c*, as a whole, is pivoted at *e* and is moved through rod *f* by piston *g* operating in cylinder *h*. Any arcing between contacts a' and b'

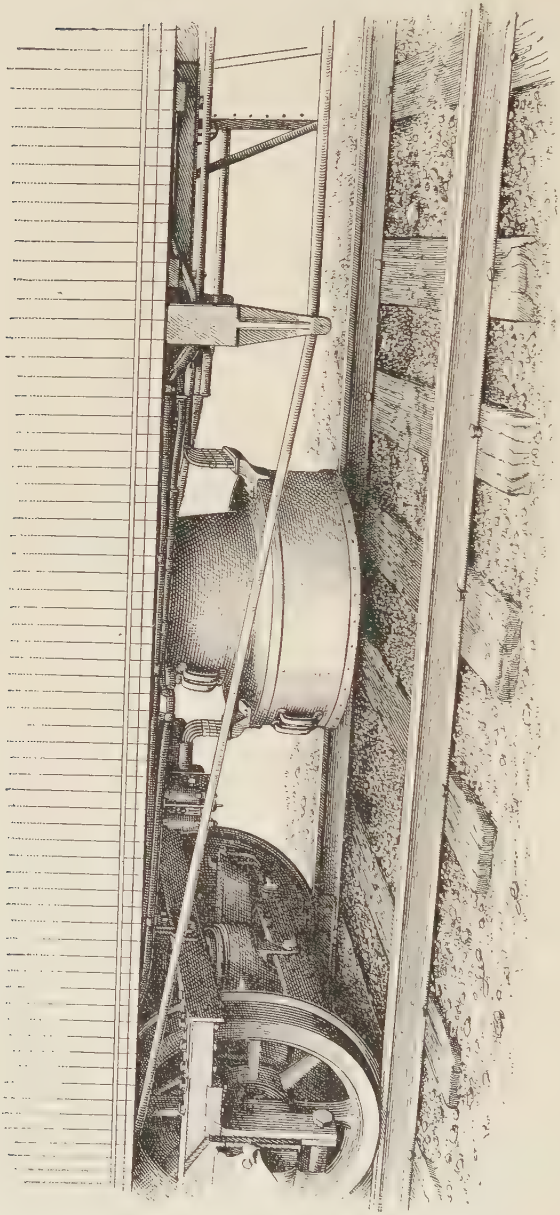


FIG. 2

takes place in chamber *i*. The radial arms *j* and *k* form poles projecting from the top and bottom of the blow-out coil. A strong magnetic field is therefore set up across the region in which the switch contacts are located and the arc is blown out radially. The object of giving the contact arm *c* limited movement around pin *d* as a center in conjunction with the small compression spring *l* is to give contacts a', b' a certain amount of wiping action that prevents sticking. The compressed air for operating the switches passes through pipe *m* into a central chamber, or reservoir, *n* of ample storage capacity, to insure that ample pressure for operating the switches is always available. Admission of reservoir air to the operating cylinders of the switches is governed by electrically operated valves that are, in turn, dependent on the master controller for action. Each switch has a cylinder and operating coil above it, the coil being enclosed in a small iron case. The relative positions of the coil case, switch, and cylinder are shown in Fig. 4. Admission of air into cylinder *h*, Fig. 4, forces the piston down and closes the switch against the action of spring *o*, the object of which is to open the switch promptly on exhausting the air from the cylinder. Over certain of the operating cylinders, small switches *p*, called *interlocks*, are arranged to be operated by the movements of the piston within the cylinder; these interlocks are used in connection with certain automatic features that will be better understood after considering Figs. 16 and 17, which are diagrams of connections. In Fig. 3, wires *q* carry the control current to the electromagnetic valves; the main current wires connect to terminals *r*, *r*.

MASTER CONTROLLER

4. The standard **master controller** used for operating either single cars or trains equipped with the Westinghouse unit-switch system is illustrated in Figs. 5 and 6, which show the device with the cover on and off, respectively. In Fig. 5, the operating handle *a* is at the off-position, corresponding to the off-position of cylinder a', Fig. 6. The cylinder a'

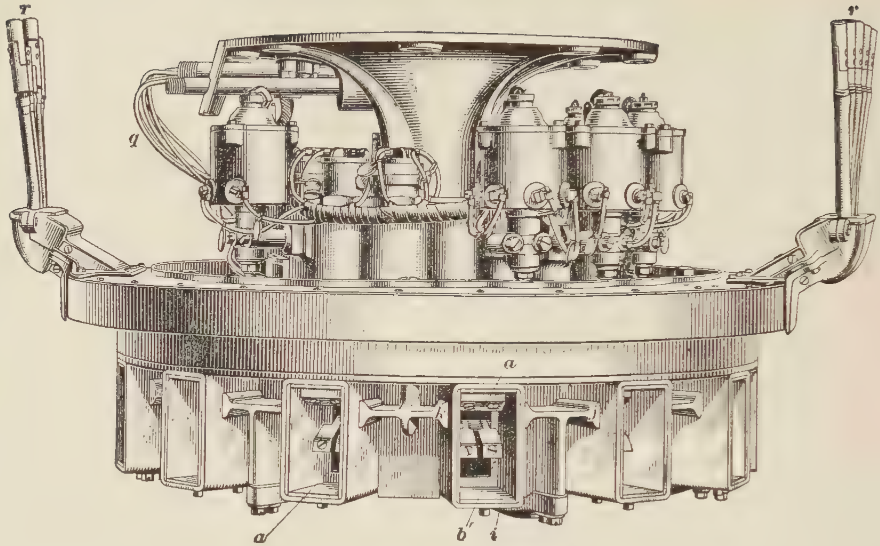


FIG. 3

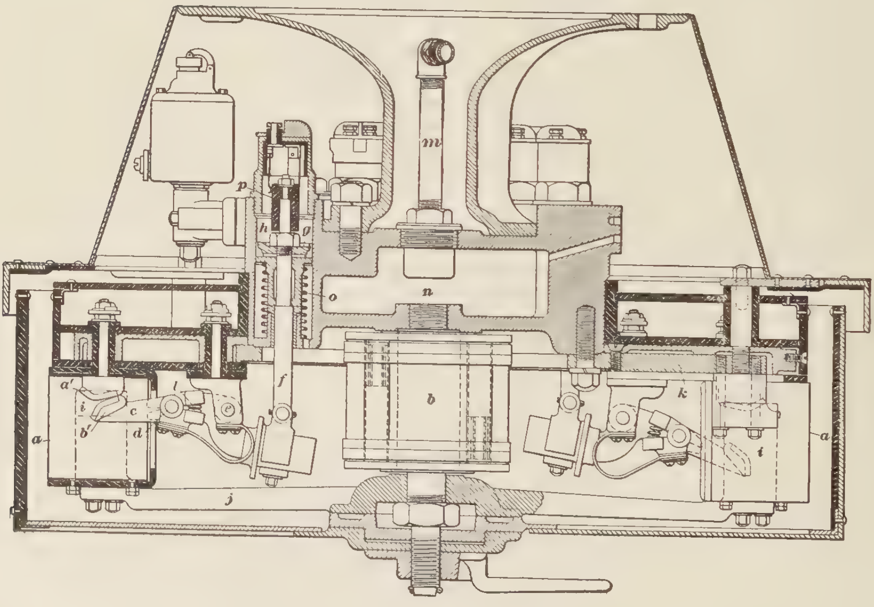


FIG. 4

consists of a single metal spider mounted on a horizontal shaft *b*, the turning of which causes the cylinder to engage fingers *c*, *c*. The operating handle can be placed in position only when the controller cylinder is at the off-position, and to rotate the handle, pin *d* must be depressed, thus raising a small lever that interferes with lugs cast on the cover. A movement of the operating handle to the right corresponds to a forward motion of the car or train, and a movement to the left reverses the motion. If the operating handle is moved to the position marked by lug *g*, Fig. 5, circuit combinations will automatically change until the motors are in full series across the line. As long as the operating handle is kept in this position, the combinations will not change, but an advance to the position marked by lug *h* will automatically change the combination until the motors are in parallel across the line. If the handle is

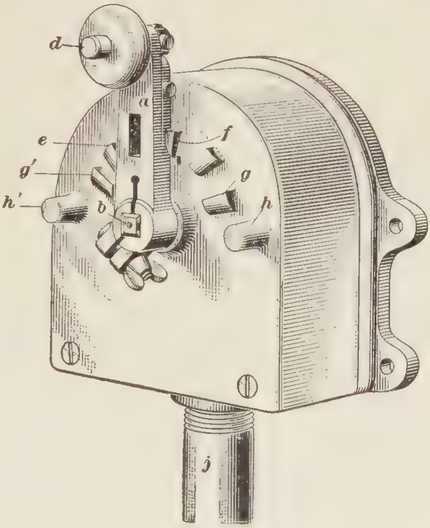


FIG. 5

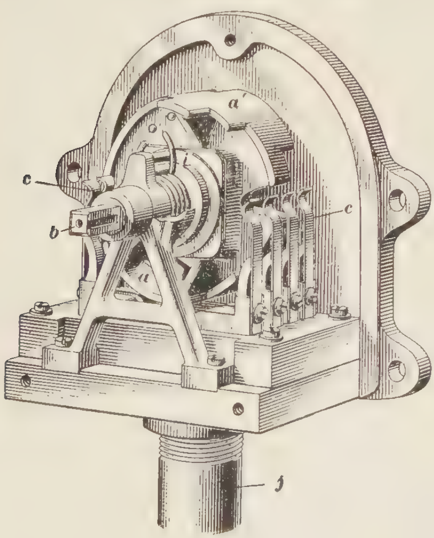


FIG. 6

released at any stage of its operation, spring *i*, Fig. 6, will return it to off-position, in which all circuits are automatically interrupted.

The first stage of the movement of the handle from its off-position throws all reversing devices to a position corresponding to the direction in which it is desired to move the car or train, provided the reverser does not already occupy a position corresponding to the desired movement. This movement also allows a flow of current through the motor circuit. This current, however, is too small to start the car, the maximum starting-coil resistance being in circuit. On the forward side of the master controller, the position on which these preliminary circuits are established is not indicated; on the reverse side, however, an additional lug *e*, Fig. 5, is provided. In emergency cases of reversal, it is well to pause on position *e*, for while the current flow on that position is insufficient to start a car, it is able to apply considerable braking action in reversal as the line electromotive force and the counter electromotive force add together, and a pause there lessens the likelihood of tripping the line circuit-breaker. If the reversing devices are not in the proper position, the motor circuit can take no current.

Fig. 7

The control-circuit wires are introduced into the master controller through pipe *j*, which may also serve as a leg for steadying the device. As $16\frac{1}{2}$ volts is the maximum pressure to which the control circuit is subjected, no difficult insulation problems are encountered, and the use of a magnetic blow-out coil for extinguishing arcs in the controller is unnecessary. Fig. 7 shows the location of the master controller in the special compartment, on an elevated-railway car, provided for the master controller and the air-brake operating devices.

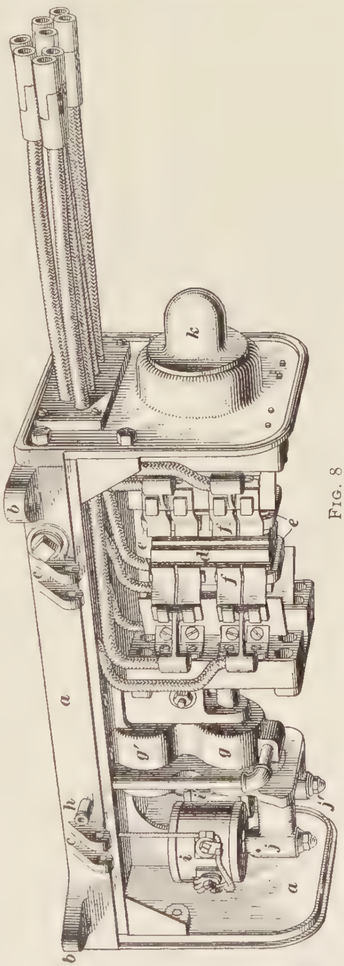


Fig. 8

REVERSE SWITCH

5. A general view of the **reverse switch,** or **reverser,** used with the unit-switch system of control is shown in Fig. 8. The function of the reverser is to interchange the main motor armature connections so as to reverse the direction of rotation of the armatures. In Fig. 8, *a* is the base and *b* the feet for securing the device to the under side of the car, *c*, *c* being the lugs to which the cover is attached. The construction and operation of the reverser are as follows: An insulating block *d* carries two sets of metal strips *e*, of which one set or the other, according to the position of block *d*, engages stationary fingers *f*. By means of compressed air admitted to cylinder *g* or *g*′, a reciprocating

motion can be given to block *d*. Electromagnets *i*, *i'* operating valves *j*, *j'* immediately beneath them determine which of the cylinders *g*, *g'* shall receive compressed air and thereby determine the position of block *d*. If the master controller is at the forward position, electromagnet *i* will be energized and will operate the valve that admits air to the cylinder, thus forcing block *d* and its contacts to a position where the train movement will be forwards. Movement of the master controller to the reverse side of its off-position will energize electromagnet *i'*, thereby operating the reverser so as to give the car or train backward motion. The reverser has no off-position, and as it is never required to interrupt a circuit that is carrying current, it has no blow-out coil for extinguishing arcs at the contact fingers. Protected by cover *k* is a small interlocking switch, the movable contact of which is attached to the reciprocating switch block; the contacts of this switch are indicated in Fig. 17. The function of the interlock is to insure that the switch group cannot operate unless the reverser has been fully thrown in the direction indicated by the master controller. The first circuit established when operating the master controller is one that insures that motor current cannot flow unless the reverser is in the correct position; this precludes the possibility of having different cars in the same train with their reversers in opposite directions.

MOTOR CUT-OUT SWITCH

6. Figs. 9 and 10 illustrate the cut-out switch used when one or both motors have to be cut out of service. Stem *b* passes through the car floor and terminates in a hand wheel, by means of which the switch can be turned to any of four indicated positions, which are as follows: (1) Both motors in circuit; (2) No. 1 motor in, No. 2 motor cut out; (3) No. 2 motor in, No. 1 motor cut out; (4) both motors cut out. In both figures, the motor wires enter the switch casing at *c*, and two control-circuit wires at *d*. In Fig. 10, *e* is one of ten contact segments mounted on a cylinder operated by stem *b*.

The motor-current fingers are shown at g mounted on insulated studs h secured to the casing. Small fingers i, i constitute an interlock whereby the unit switches are unable to create any parallel motor combination except when both motors are cut in.

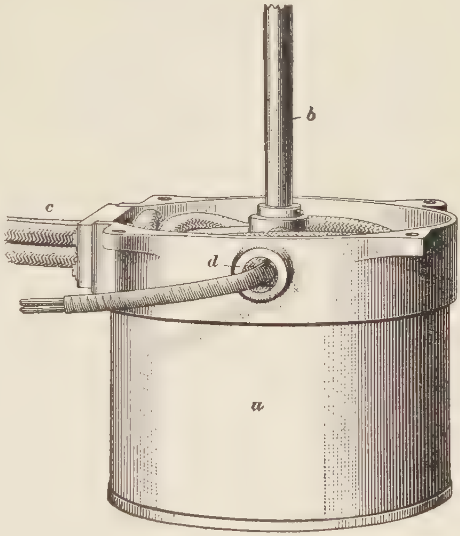


FIG. 9

TRAIN-LINE COUPLER

7. The control-circuit train cables of abutting cars are coupled by means of devices similar to those described in connection with the type M system of control, but as the unit-switch system employs only seven wires at a maximum difference of potential of 16 volts, the coupling devices are smaller than those required to handle the line voltage. Fig. 11 shows one of the flexible connections used between cars. The coupling heads, or plugs, a consist of a malleable-iron shell surrounding a cylindrical piece of insulating material, in which are set seven small brass receptacles. Permanently

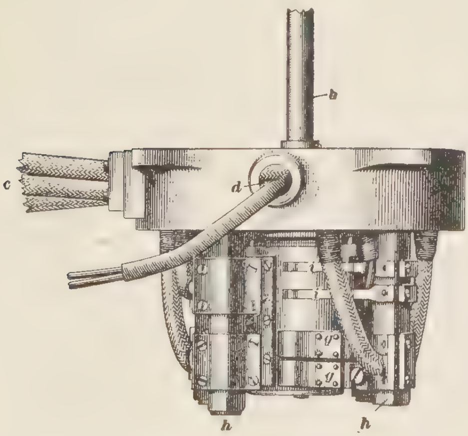


FIG. 10

mounted on the ends of all cars to be made up into trains are two sockets, each containing seven split pins mounted on an insulating base. Each split pin in a socket enters a corresponding receptacle in the plug, thereby connecting a certain control wire on one car to the same control wire on the abutting car and preserving the individuality of each wire throughout the length of the train.

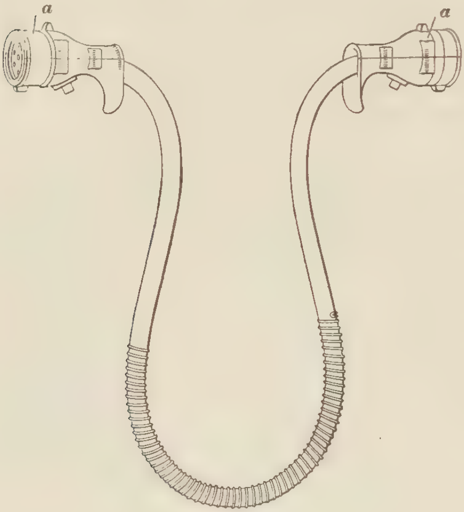


FIG. 11

LIMIT SWITCH

8. Fig. 12 illustrates the **limit switch,** the object of which is to regulate the rate of acceleration by stopping the

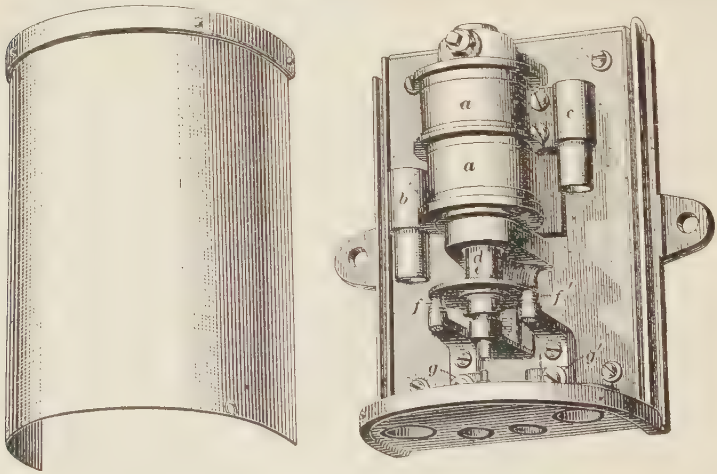


FIG. 12

progressive action of the unit switches whenever the motor

current exceeds a predetermined value. In Fig. 12, *a* is the operating coil of which *b* and *c* are motor-circuit terminals; *d* is an iron plunger carrying at its lower end a metal disk *e*, which normally rests on contact points f, f' that connect to control-circuit terminals g, g', respectively. The operating coil of the limit switch is connected in series with the negative side of the No. 1 motor field, and the switch device composed of disk *e*, contacts f, f', and terminals g, g' is connected in series with the *L* branch of the No. *4* wire (see wiring diagram, Fig. 17), which is the positive battery connection for the pick-up coils of all unit-switch magnets except *5*, *6*, *7*, and *8*. The limit switch can be adjusted to open at any predetermined motor current, and the opening of the switch opens the circuit leading to the pick-up coils of all unit switches except those stated. These switches will not be closed until a decrease in the motor current allows disk *e* to drop and close the limit-switch contacts. To illustrate, suppose the No. *9* switch, Fig. 17, to close, and the motor current on that notch to be 250 amperes, the value at which the limit switch is set to operate being 240 amperes. The limit switch will operate immediately and arrest any further progressive action of unit switches, but will not cause those unit switches already closed to open. The limit switch is distinctly an acceleration regulator, making the rate of acceleration largely automatic and preventing excessive current consumption and wheel slippage due to careless handling of the controller.

LINE SWITCH

9. Figs. 13 and 14 are, respectively, a front and a back view of the **line switch**, which is essentially an automatic circuit-breaker, and Fig. 15 is a view with the cover removed. Corresponding parts are marked the same in the three views, and their connections will be understood by referring to Fig. 17. In Fig. 15, *a a* is the blow-out coil, which also serves as a tripping coil, wound in two sections and composed of copper strip coiled on edge; *b* is the air cylinder in

which a piston moves back and forth, thus separating contacts *c*, *d* or bringing them together, as the case may be, and thereby opening or closing the main motor circuit. Magnet coil *e* controls the position of enclosed valve *f*, through which

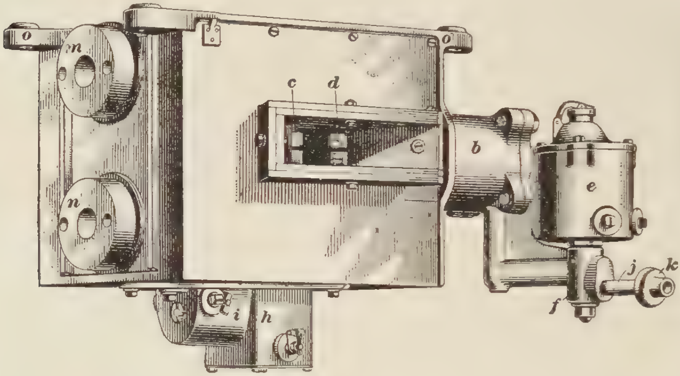


FIG. 13

air is admitted to cylinder *b*, and an interlock switch is enclosed in *g*. The circuit-breaker tripping device is shown at *h*, and the resetting device at *i*. Operating air enters

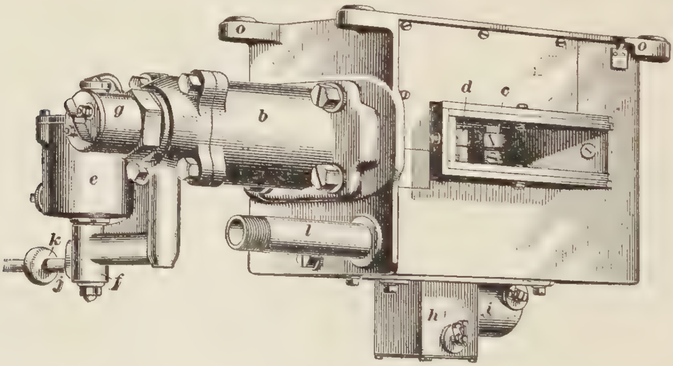


FIG. 14

through pipe *j*, which includes an insulation coupling *k*, Fig. 13, to prevent grounding the line-switch casing through the piping system. The control wires enter and leave through pipe *l*, Fig. 15, and the motor-circuit wires through

wooden bushings *m* and *n*. Motor current entering the breaker passes successively through top blow-out coil section, contacts *c* and *d*, and bottom blow-out coil section.

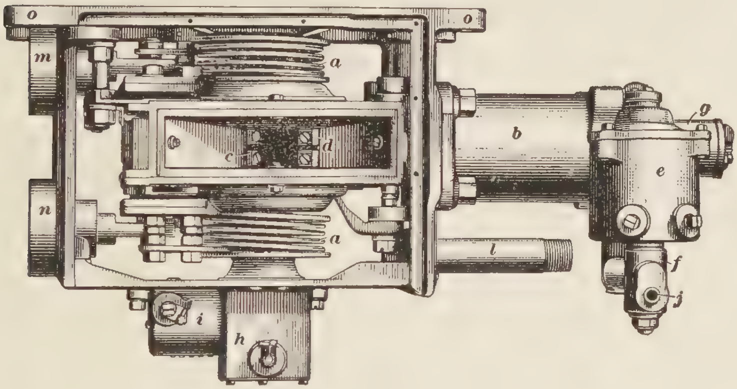


FIG. 15

The lugs for supporting the device from the under side of the car are shown at *o*.

10. The line switch, or circuit-breaker, is connected between the trolley and the unit-switch group, as indicated in Fig. 17. When the trip is opened, it is held open by a catch that can be withdrawn either by hand operation or by momentarily closing the circuit through the reset coil by closing the circuit-breaker reset switch located alongside the master controller. This can be done only when the master controller is at off-position. The armature of the overload trip works against a spring that can be adjusted for different values of the tripping current. The object of the line-switch interlock, which is closed only when the line switch is open, is to short-circuit the contacts of the line relay and thereby permit operation of the switch group for testing purposes, without the possibility of establishing any main circuits that can allow current to flow. The line switch is not always used, and in the equipment shown in Fig. 1, it is not indicated.

LINE RELAY

11. The function of the **line relay**, the connections of which are indicated diagrammatically in the lower right-hand corner of Fig. 17, is to open all the switches except the line switch when there is no power on the line. One terminal of the relay-operating coil is connected through a resistance to the inside of the line switch, and the other terminal to the ground. The relay contact marked *8* is connected to one contact of the overload trip switch, to $B-$ side of the line-switch magnet coil, and to one side of the line-switch interlock. The other relay contact *S* connects to the opposite side of the line-switch interlock and also to one contact of the No. *6* unit-switch interlock. The result of these connections is to make the line-relay switch the return battery wire for all switch coils except that of the line switch. The line-relay switch is normally held open by gravity; but closing the line switch, the operating coil of which does not depend on the line-relay switch for its battery return, provides a trolley connection from which current flows through the line-relay operating coil. This current closes the line-relay switch, which remains closed as long as the line switch is closed, the latter being open only when the master controller is at off-position or when the overload trip switch operates.

RESISTANCE COIL

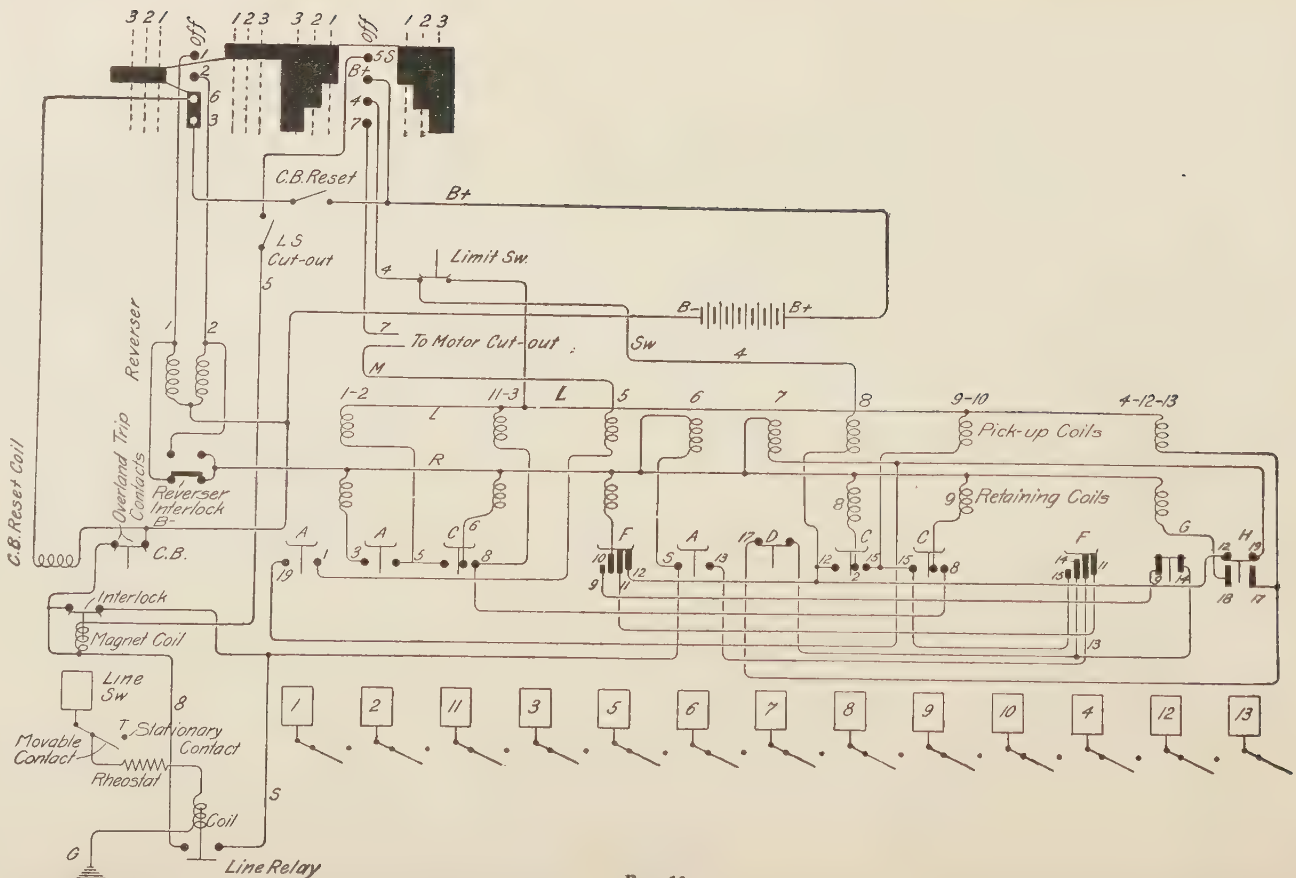
12. The resistance employed with the unit-switch control equipment is of the Westinghouse grid type, and is made up of eleven units, the connections of which are indicated in Fig. 17. The grids are grouped to form seven resistance sections, and in parallel with each section is a corresponding unit switch, the closing of which short-circuits the section.

CONNECTIONS AND OPERATION

13. The connections of the control, or operating, circuit for a single car are shown in Fig. 16, the wiring being simplified somewhat in order to make the circuits easier to

follow. For example, a single set of cells connected directly to the controller is shown for supplying the control current, while in an actual installation two sets of cells are used, as shown in Fig. 17, and are connected to switches so that one set can be charged while the other is in use. Also, the seven control wires pass from end to end of the car, as indicated in Fig. 17, and terminate in sockets. In Fig. 16, the wiring is shown as applying to a single car, but in following out the operations it should be remembered that the movement of the master controller on the front car, or any other car of a train, operates the main controllers on all the motor cars, because the control circuits pass from car to car and are energized throughout the train. The unit switches, without main-current connections, are shown numbered in the lower part of the figure. The small switches shown above the unit switches *1*, *2*, *4*, *5*, *6*, *7*, *8*, *9*, *11*, *12*, and *13* represent the interlocks. Where the crosspiece of these small switches is shown a short distance above the terminals of the switch, it indicates that the interlock is open when the corresponding main switch is open, and that when the piston of the main switch goes down the interlock closes. When the crosspiece is shown below, but in contact with the terminals, it indicates that the interlock opens when the piston goes down and the main switch closes.

In Fig. 16, the interlocks on unit switches *1*, *2*, *6*, *8*, *9*, and *11* are open and those on unit switches *7*, *12*, and *13* are closed, the unit switches themselves being all open. The construction of the interlocks on unit switches *4* and *5* is different from that of the others. The curved crosspiece, represented as touching the two right-hand long strips, slides up and down with the piston. Soon after the piston starts its downward movement, the third strip from the right makes contact with the sliding crosspiece. Just before the piston reaches the end of its downward stroke, the sliding contact engages the left-hand short strip, but leaves the extreme right-hand strip marked *12* on the interlock of switch *5*, and *11* on that of switch *4*. Certain of the unit switches are provided with two coils, one of which is a



off
C.B. Reset
B+
L S
Cut-out
Limit Sw.
B-
B+
Sw
To Motor Cut-out
Reverser
1-2
11-3
L
R
Pick-up Coils
Retaining Coils
C.B. Reset Coil
Overland Trip
Contacts
Reverser
Interlock
C.B.
Interlock
Magnet Coil
Line
Sw
Movable
Contact
Stationary
Contact
Rheostat
Coil
Line Relay

Fig. 16

pick-up coil for operating the switch and the other a retaining, or holding, coil for holding the switch closed even if current is cut off from the operating coil. The object of the retaining coils will be better understood after the operation on the various controller notches has been considered; but, briefly, their function is to hold such switches as may have already operated closed, even though the limit switch, because of excessive current, opens and thus prevents any other unit switches from closing. That is, the holding coils prevent all the switches from opening and thus making it necessary to cut out the resistance again from the beginning.

14. Operation on First Position.—Movement of the master switch handle to its first forward position establishes connections as follows: Master controller finger $B+$, connected to the positive battery terminal, connects to fingers *5S* and *1* through the master controller cylinder. Assuming the line-switch cut-out to be closed, finger *5S* introduces current through the magnet coil of the line switch, and this current reaches the negative battery wire by way of the overload trip contacts; excitation of this circuit closes the line switch by admitting air to its operating cylinder. The closing of the line switch provides a trolley connection at T, and allows current to flow through the lifting coil of the line relay to ground, thereby closing the line-relay switch, the contacts of which are in parallel with the line-switch interlock. A small rheostat is connected in series with the line-relay coil to limit the current. Simultaneously, a current from finger *1* passes through reverser coil *1* and thence to the negative side of the battery. This current opens the valve controlled by reverser coil *1*, and if the reverser is not already in the forward position, it will promptly move to this position. As soon as the reverser throws the full length of its travel, the safety switch on the end establishes connection between the positive battery wire $B+$ and wire R, which represents the positive sides of the retaining coils Nos. *1–2*, *11–3*, *5*, *8*, *9–10*, *4–12–13*, and the pick-up coils Nos. *6* and *7*.

The reverser must be fully thrown forward or back, otherwise its safety switch will not connect wire *R* to battery. Assuming the reverser to be at the extreme end of its travel, wire *R* will become $B+$, and current passes through the No. *6* magnet coil to $B-$ by way of the closed line-relay switch, thereby operating the No. *6* unit switch and closing its interlock *S–A–13*. The closing of this interlock causes current to take path *R*–No. *7* magnet coil–contacts *19*, *12* of unit switch *13*–contacts *12*, *11* of interlock *5*–contacts *11*, *13* of interlock *4*–contacts *13*, *A*, *S* of interlock *6*, here joining with the current from the No. *6* magnet coil and flowing with it through the line-relay switch to $B-$, and thereby operating unit switch *7*. The motors are now in series with resistance, as will be seen by tracing out the main-current path in Fig. 17, assuming the line switch and unit switches *6* and *7* to be closed; also, see Table I.

15. Operation on Second Position.—On moving the master controller to the second position, thereby connecting controller finger *4*, Fig. 16, to $B+$, current flows out on the No. *4* wire, through the magnet coil of switch *8*, which immediately operates, through interlocks of switches *5*, *4*, and *6* to join in with the operating currents of switches *6* and *7*, and through the line relay switch to $B-$. Through the limit switch, a branch of the No. *4* wire connects to wire *L*, which is the positive side of the pick-up coils of magnets *9–10*, *11–3*, *1–2*, and *4–12–13*. The closing of No. *8* interlock, due to the operation of No. *8* unit switch, has given a $B-$ connection to the No. *8* retaining coil and also to the No. *9–10* pick-up coil, which closes switches *9* and *10*. The closing of switch *9* gives its retaining coil a $B-$ connection through its own interlock and interlocks of switches *8*, *5*, *4*, and *6*. The operation of unit switch *9* also gives a $B-$ connection to pick-up coil *11–3*, which immediately picks up unit switches *11* and *3*. These switches are retained by their retaining coil, which gets its $B-$ connection through interlocks *11*, *9*, *8*, *5*, *4*, and *6*. The closing of unit switch No. *11* closes its interlock, through which a $B-$ connection is given

to the pick-up coil of No. *1–2* magnet. This magnet picks up switches Nos. *1* and *2*, which are then retained by their retaining coil, getting a $B-$ connection through interlocks of switches *2*, *11*, *9*, *8*, *5*, *4*, and *6*. The motors are now in full series across the line.

16. Operation on Third Position.—On moving the master switch to the third position, finger $B+$ is connected to the No. *7* wire and battery current takes path *7*–motor cut-out switch–interlock wire *M*–pick-up coil *5*–interlocks of switches *1*, *13*, *5*, *4*, *6*–$B-$, by way of the line relay, as in preceding cases. The closing of No. *5* switch first completes the circuit of its own retaining coil through contacts *10* and *11* on No. *5* interlock, contacts *11* and *13* on No. *4* interlock, No. *6* interlock to $B-$, as usual. Toward the end of the piston stroke, the sliding contact on interlock No. *5* breaks connection with contact No. *12*, thereby depriving the pick-up and retaining coils *7*, *8*, *9–10*, *11–3*, and *1–2* of their $B-$ connections and opening these switches. When No. *5* switch is fully closed, the short contact of its interlock completes the circuit through the pick-up coil *4–12–13* as follows: $B+$ –*4*–pick-up coil *4–12–13*–interlock on switch *7*–interlock on switch *12*–interlock on *5*–interlock on *4*–interlock on *6*–line relay–$B-$. Switches *4*, *12*, and *13* do not close until switch *7* has fully opened, because interlock *7* is part of the circuit through pick-up coil *4–12–13*, and this interlock is closed only when its unit switch is entirely open. When switch No. *13* closes, its lower interlock contacts establish a $B-$ connection to the retaining coil through interlocks *13–7–12–5–4* and *6*. In the first part of the downward movement of the piston of switch No. *4*, its interlock engages the low contact, thereby establishing another $B-$ path through the Nos. *14* and *13* fingers of the interlock of switch *4*. The first path is broken in two places by operation of unit switches *1* and *12* when these switches are nearly closed and the $B-$ connection of the retaining coil of switch No. *5* is also broken; this switch then opens. The motors are now in parallel and have five sections of resistance in series with

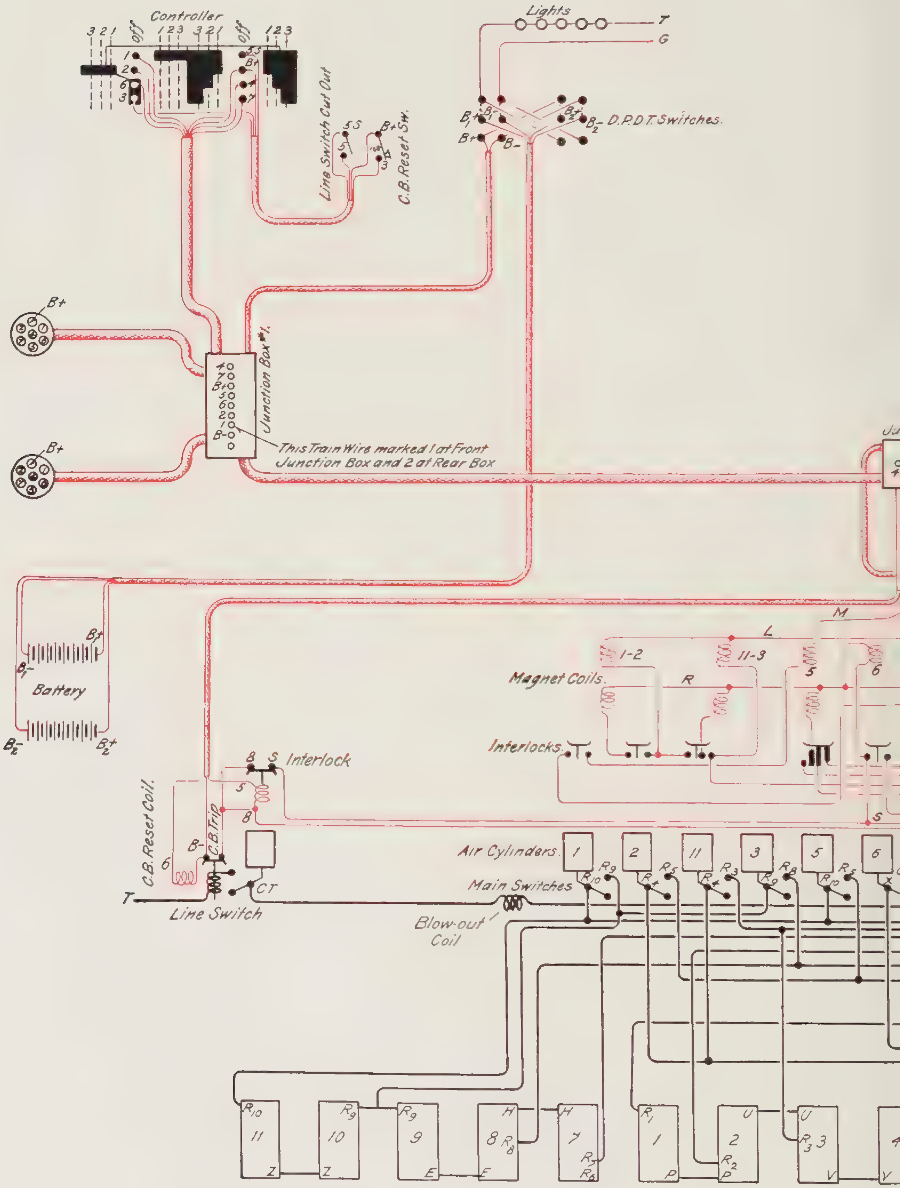
each. The full closing of switch No. *4* connects the short contact of its interlock to $B-$, thereby providing a $B-$ connection for the pick-up coil of the *9–10* magnet, which picks up switches *9* and *10*. The closing of switch No. *9* causes the consecutive closing of *11–3* and *1–2*, as on the second position. The motors are now in full parallel and will remain so until the master controller is moved to off-position.

CAR-WIRING DIAGRAM FOR UNIT-SWITCH CONTROL

17. Fig. 17 is a car-wiring diagram of the unit-switch system and shows the main motor connections that are omitted in Fig. 16. In Fig. 17, the normal condition of a unit-switch equipment with a train at a standstill, is as follows: The master controllers are both at off-position; all unit switches, the line switch, the line-switch cut-out and circuit-breaker resetting switches (see small switches near master controllers) are open. One battery of storage cells is ready for use and the other is charging through the lamp circuit. The reverser is either in forward or reverse position, and the motor cut-out switch is on the first position in which both motors are cut in. The line-relay switch is open and the limit switch is closed.

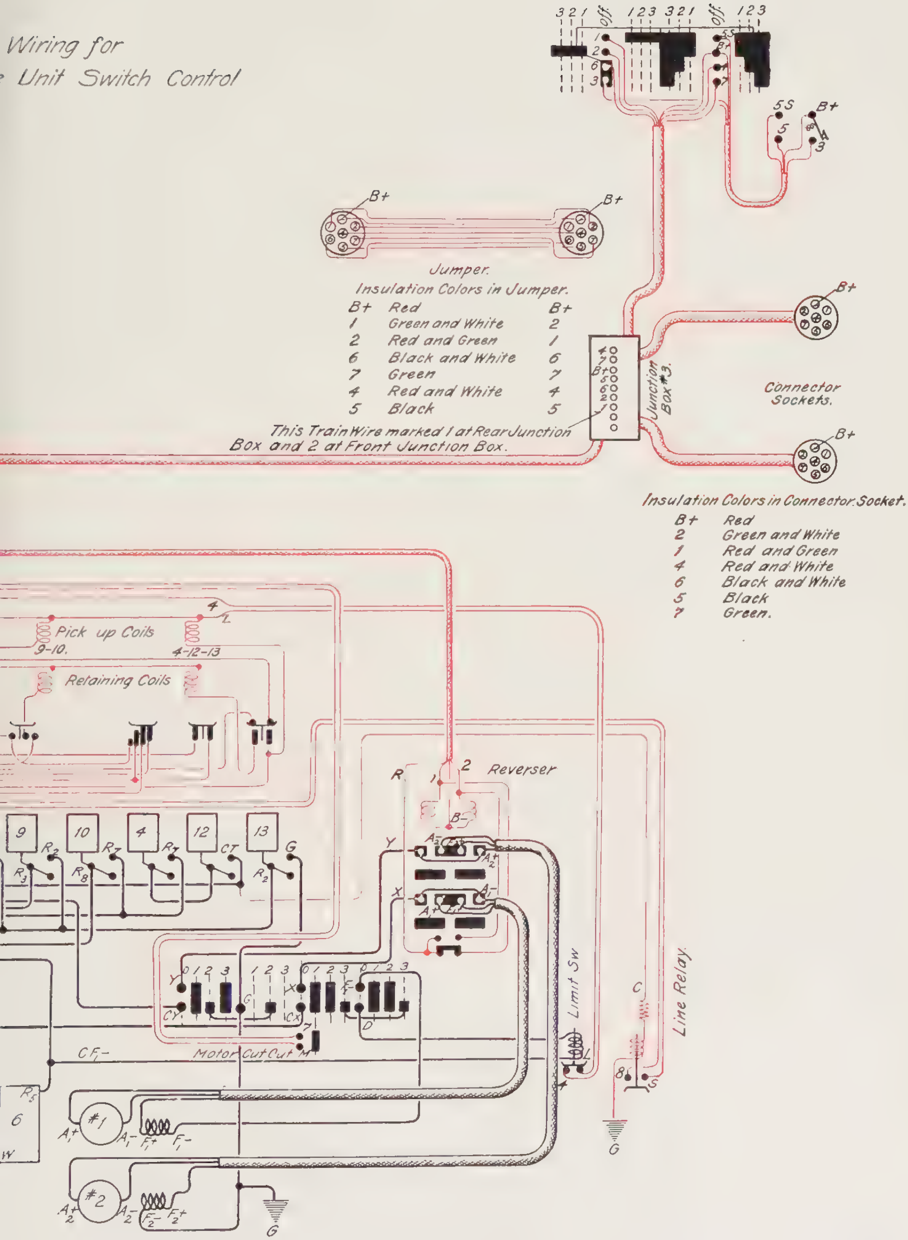
18. A motorman on taking a car, first closes the pump switch and raises the air pressure to a standard value. The line-switch cut-out is then closed, and the resetting switch is closed for an instant to insure that the circuit-breaker trip may be at the upper end of its stroke, where it provides return battery connection $B-$ not only for the magnet coil of the line switch but also for the several control-circuit arrangements.

The circuit-breaker resetting coil is operative only when the master switch is at off-position, because only in this position are master-controller fingers *6* and *3*, which are part of the resetting circuit, connected. With the circuit-breaking trip of the line switch closed, one of the first effects of advancing the master controller to the first position is to energize the line-switch magnet coil, thereby admitting air



Controller
Lights
D.P.D.T. Switches.
Line Switch Cut Out
C.B. Reset Sw.
Junction Box #1.
This Train Wire marked 1 at Front Junction Box and 2 at Rear Box
Battery
Magnet Coils.
Interlocks.
Interlock
C.B. Reset Coil.
C.B. Trip
Line Switch
Air Cylinders.
Main Switches
Blow-out Coil

Wiring for
Unit Switch Control



to the line-switch operating cylinder, closing the main circuit-breaker contacts, and opening the line-switch interlock. The immediate effect of closing the line-switch main contacts is to send current through the magnet coil of the line relay and thereby close the line-relay switch. It must be remembered that the line-relay switch handles battery current, but its magnet coil is energized by line current. The closing of the line-relay switch provides the $B-$ return for the various control circuits connecting to the No. *6* interlock, as considered in connection with Fig. 16. As line voltage is necessary to keep the relay switch closed, the relay switch will open all automatic switch circuits, except that of the line switch, if the power leaves the line or if the trip coil of the line switch operates. While closing the line switch renders the wire CT, Fig. 17, extending from the line switch to the unit switch No. *12*, alive, no motor current can flow until flow of current through the reverser circuit throws the reverser and establishes the safety switch $B+$, R connection that operates unit switch *6*, the operation of which sets off *7*. Moving the master controller to the series running notch automatically works the motor up to full series, and movement to the multiple notch automatically changes the motors from full series to parallel with resistance in series, then to full parallel. Should the master controller be advanced too rapidly, the limit switch will operate and open the circuit between wire *4*, Fig. 16, and the bus-wire connected to several of the pick-up coils. This will prevent any further cutting out of resistance until the current has dropped to normal value. However, the opening of the limit switch does not interfere with the current in the holding coils and the switches that have operated up to this point do not drop and cut resistance back in. By means of the various interlocks and the connections between operating coils, the cutting out of resistance is performed automatically after the controller has been placed on notch *2* or *3* and does not require a movement of the controller for each section of resistance cut out. The unit switches active at the different steps of the controller operation are indicated in Table I.

TABLE I

Sequence of Steps	Notch Number	Unit Switches in Action
1		Line switch
2		Line switch 6
3	1	Line switch 6 7
4	2	Line switch 6 7 8
5	3	Line switch 6 7 8 9–10
6	4	Line switch 6 7 8 9–10 11–3
7	5	Line switch 6 7 8 9–10 11–3 1–2 (full series)
8		Line switch 6 7 8 9–10 11–3 1–2 5
9		Line switch 6 5
10		Line switch 6 5 4–12–13
11	6	Line switch 6 4–12–13
12	7	Line switch 6 4–12–13 9–10
13	8	Line switch 6 4–12–13 9–10 11–3
14	9	Line switch 6 4–12–13 9–10 11–3 1–2 (full parallel)

SCHEDULE F-1

19. The field of operation for multiple-unit systems is constantly expanding, and in order to meet new conditions, the details of the various systems are changed from time to time. The **F-1 system** is a later development of the Westinghouse unit-switch system of multiple control than the one just described. Schedule F-1 is designed for a double equipment of motors of from 180 to 225 horsepower. Only the apparatus that has undergone considerable alteration will be here described. The general method of operation of the system remains unchanged.

UNIT-SWITCH GROUP

20. The **unit-switch group** consists of twelve independent, or unit, switches grouped together in a line on a frame that contains an air reservoir. The rectangular switch group, shown in Fig. 18, allows of easier inspection and repair than the radial, or turret, group previously described. Between the switches are arranged blow-out coils that disrupt any arc that may form at the main contacts.

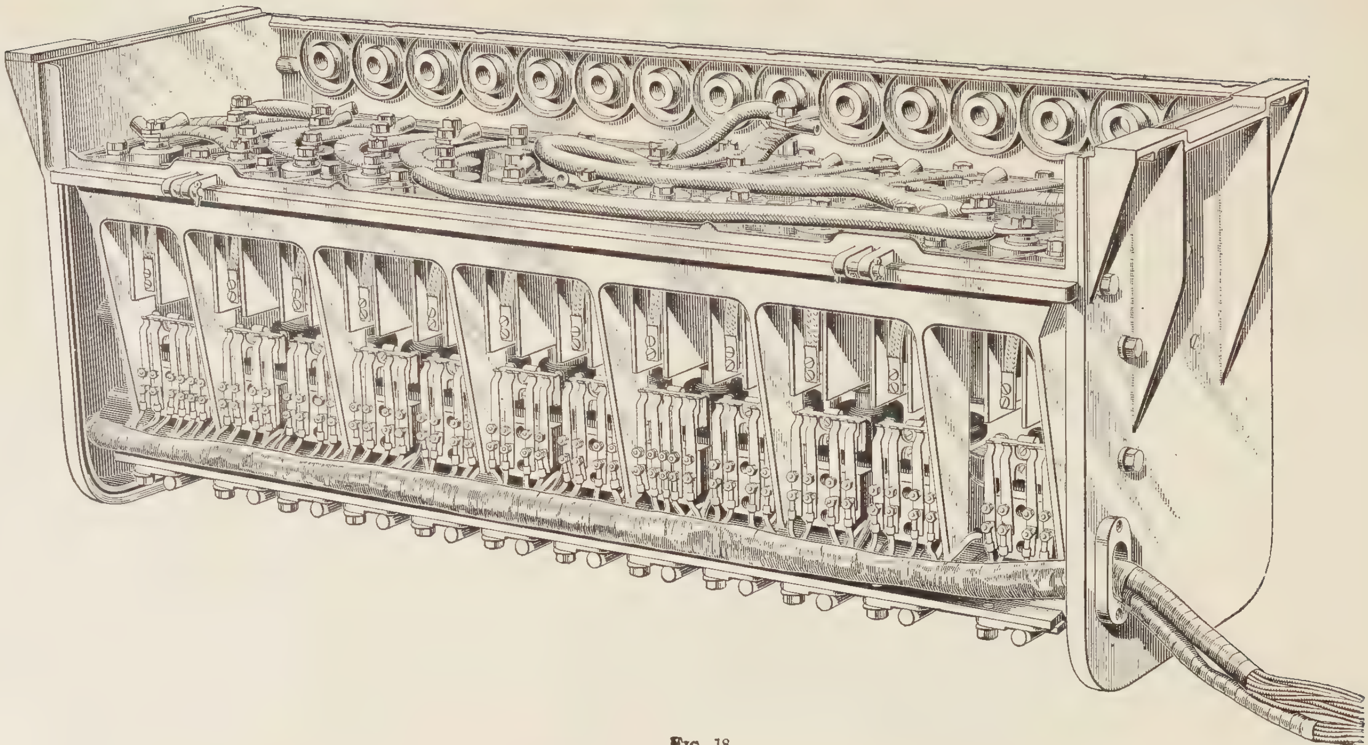


FIG. 18

Fig. 19 shows a portion of the other side of the switch group. The main contacts are located at *a*. The arcs, if

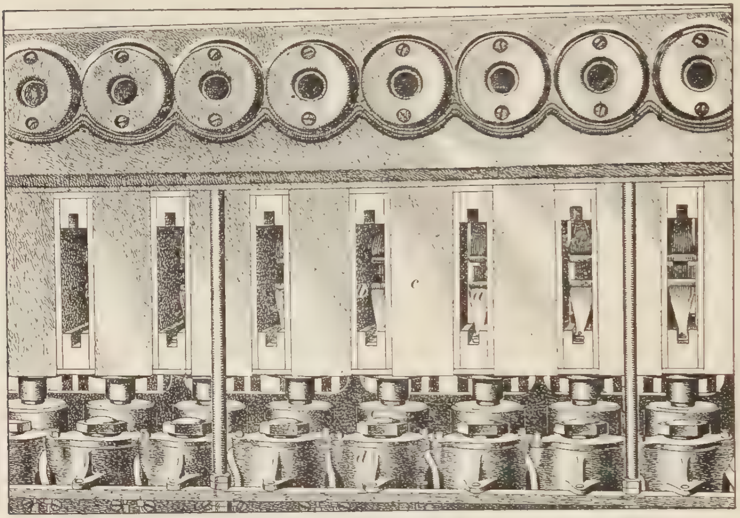


FIG. 19

formed, are blown out through the arc shields *b* by blow-out coils in *c*. The operating magnets are shown at *d*, and the operating air cylinders at *e*.

UNIT SWITCH

21. In Fig. 20 is shown a sectional view of a **unit switch.** The operating magnet *a* when energized opens its air valve and allows air, under about 70 pounds pressure per square inch, to enter the lower portion of air cylinder *b*, thus forcing the piston upwards and closing the main contacts *c*. The movable-switch contact is pivoted to the switch arm at *d*, and the arm is pivoted at *e*. A wiping action between the contacts is thus brought about as the switch closes, thus preventing sticking and causing a better contact and minimum deterioration.

On the piston rod is an arm holding a block on which are mounted interlock segments *f*, thus securing simultaneous

movement of the interlock segments and the piston. One of the interlock fingers is shown at *g*. The general arrangement of these fingers is shown in Fig. 18. The fingers are so connected with the operating magnets and inter-

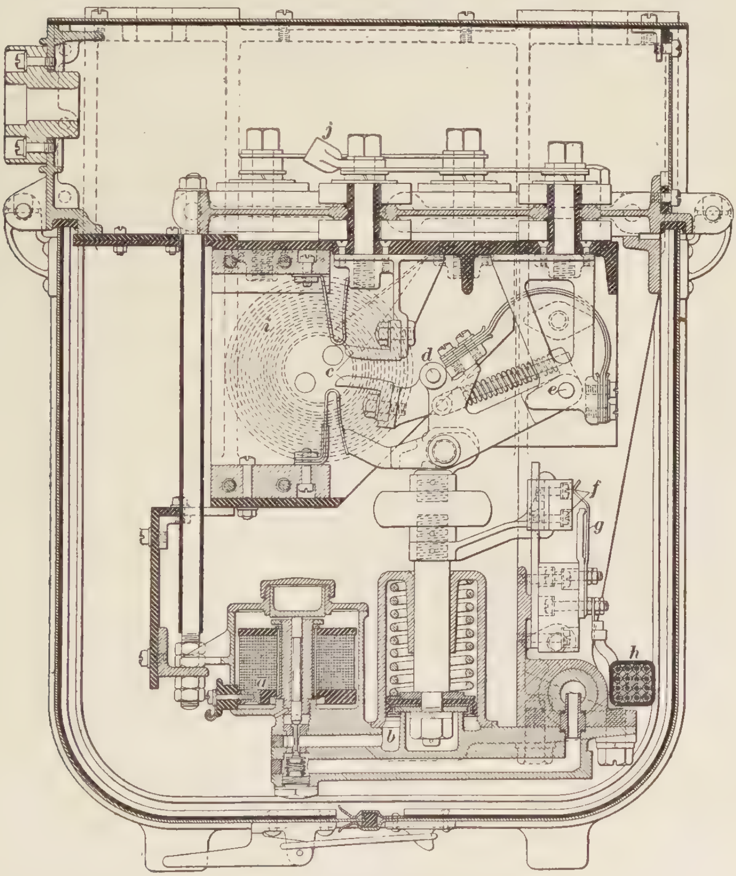


Fig. 20

lock segments that the closing of one switch energizes the magnet of the next switch to be operated, and thus produces automatic progressive action.

When the magnet circuit is opened, the magnet closes its air valve and the air cylinder exhausts to the atmosphere,

thus allowing the switch to open through the action of the cylinder piston spring. It will be noticed that the normal position of the switch is open; thus, the failure of the air supply or the interruption of the circuit opens all of the unit switches. The control-circuit wires are shown at *h*, the blow-out coil at *i*, and one of the main-circuit terminals at *j*. The connections of the switches are better shown in Fig. 23.

MOTOR-CONTROL CUT-OUT SWITCH

22. Instead of a main motor cut-out switch, a **control cut-out switch** is used in the control circuit of this system. There are a number of types of these switches. Fig. 21 shows one arrangement of fingers and segments. On the opposite side of the cylinder, there are other segments that make contact with the right-hand set of fingers as the handle is turned to the left. The four positions are: *both out*, *both in*, *No. 1 out*, and *No. 2 out*.

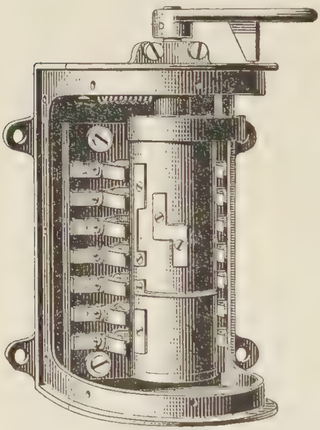


FIG. 21

Operating the switch cuts out the operating circuits of certain unit switches, thereby cutting out either one or both of the motors should they become disabled. An interlock is provided that prevents the switch group from reaching parallel position, except when both motors are in circuit.

LINE SWITCH

23. The **line switch**, as shown in Fig. 22, is a single unit switch of almost identical construction with those of the switch group. This switch is arranged as a circuit-breaker, and will open the circuit in case of an overload. A trip plunger acted on by one of the blow-out coils opens a small

switch, called the *overload trip*, in the control circuit, in case of an excessive load. The line switch and the overload trip may be closed by the operation of plug cut-out switches located near the controller and acting through the control resetting coils in the switch.

CAR-WIRING DIAGRAM

24. Action of Plug Cut-Out Switches.—In Fig. 23 is shown a car-wiring diagram for type unit-switch control, 251-C switch group, and two motors, schedule F-1. A single plug is provided for the three plug cut-out switches shown near the controller. In some cases, small, single-pole, knife switches are used in place of the plug switches. When the plug is inserted in the reset switch, the wire $B+$ is connected to wire 7–7 on motor-control cut-out (both motors in)–*70*–*70*–*73*–resetting coil of the overload trip on the line switch–*90*–interlock A of unit switch M_1–*9* wire at motor-control cut-out–$B-$. The overload trip switch is closed, if previously open.

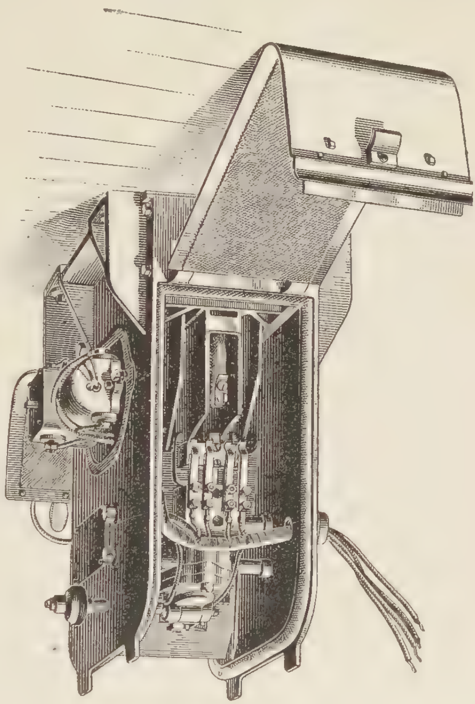


FIG. 22

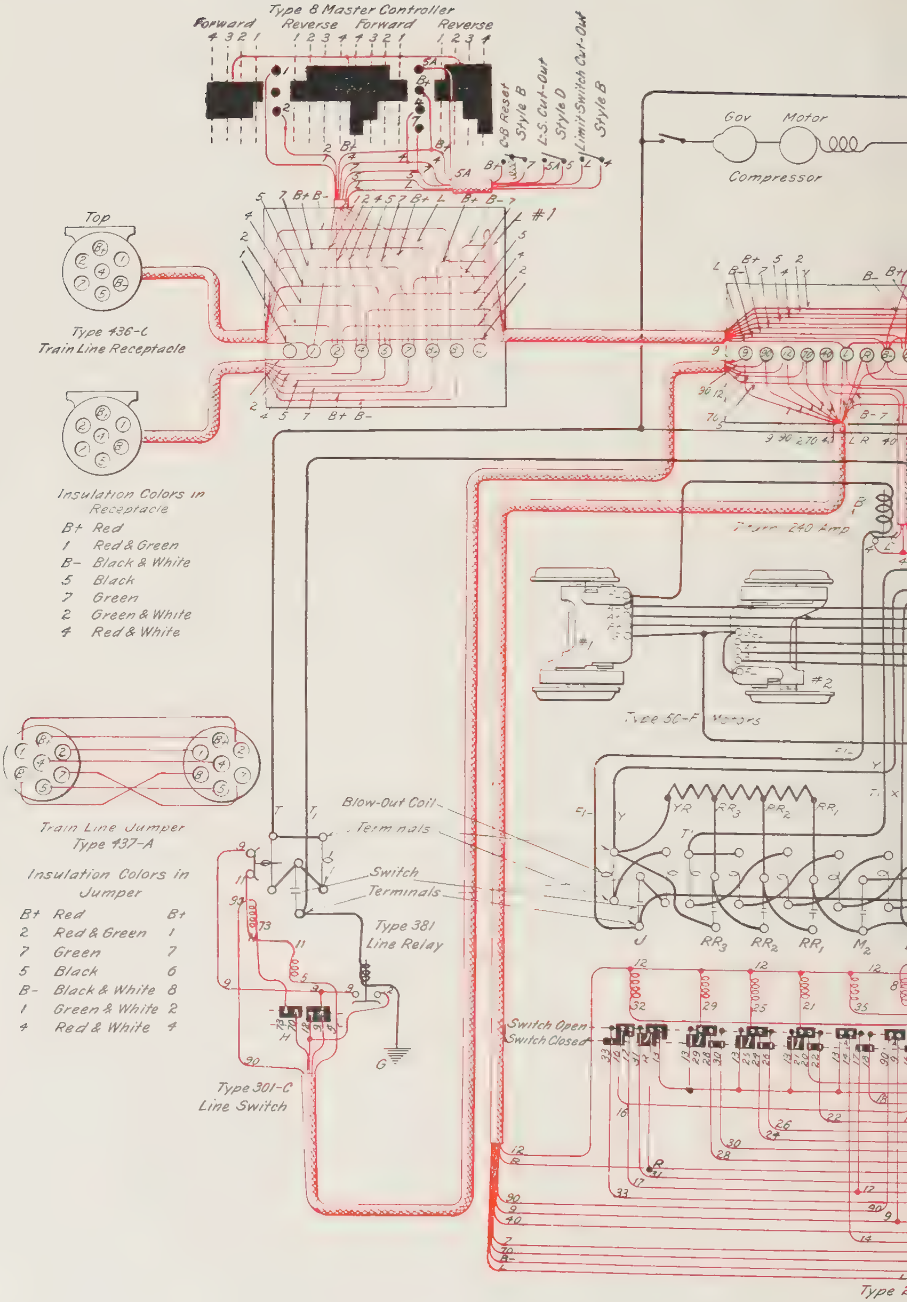
Inserting the plug in the line-switch cut-out (abbreviated *L.-S.* cut-out in Fig. 23) and moving the controller handle to either forward or reverse position, so that finger *5A* is active, completes the circuit through wire *5*, the

resetting coil of the line switch and wire *9*, thus closing the switch. When the line-switch cut-out is open, the line switches throughout the train cannot be closed, and no circuit can be established from the line.

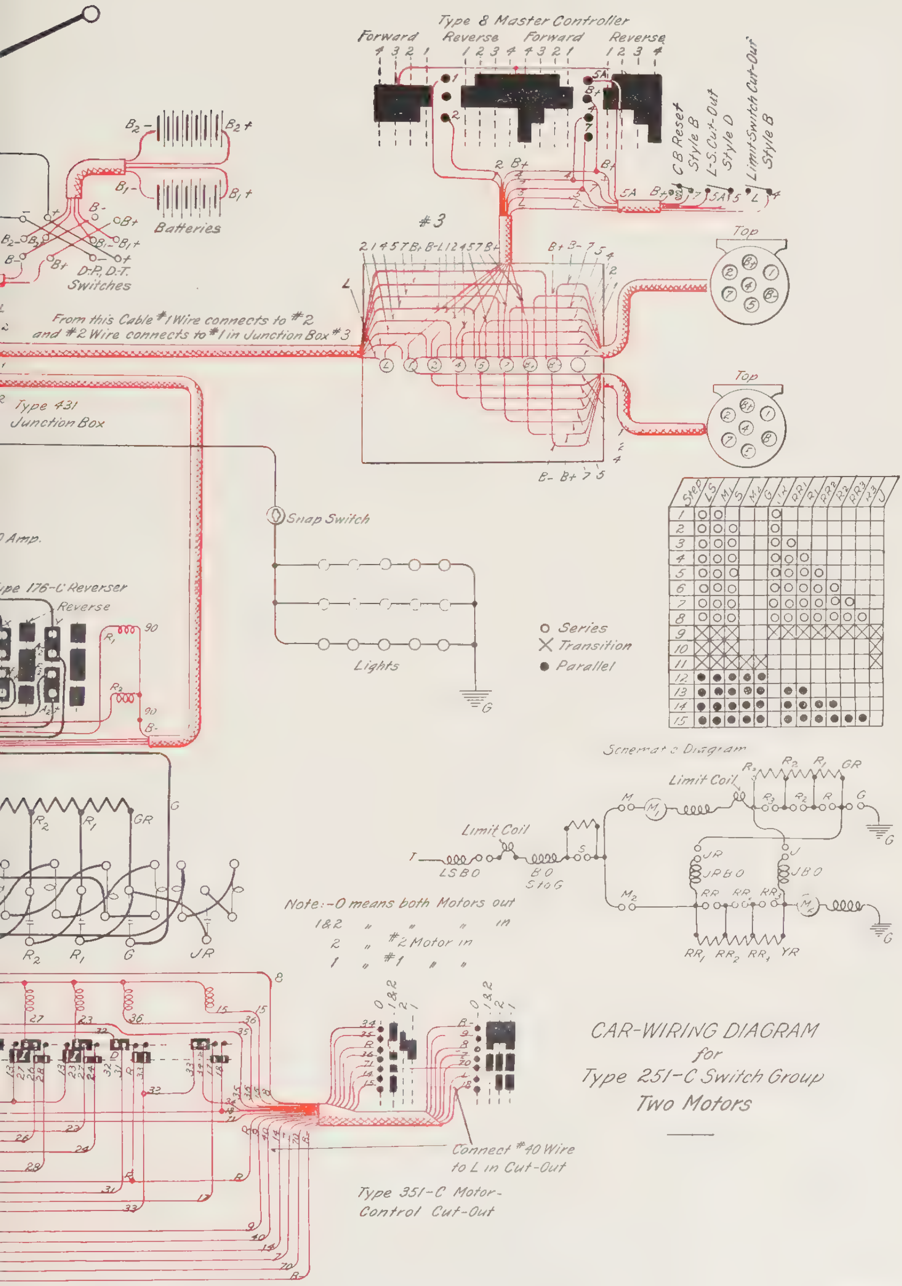
When the line switch is open, the line relay is also open. The line-relay contacts *9* and *12* are connected to fingers *9* and *12* on the line-switch interlock, and these fingers are connected together by the interlock when the line switch is open. The circuit of wire *12* is thus completed, and the switch group may be operated for test purposes with the motor circuit open. If the master-controller handle is thrown to parallel-running position in the reverse direction when the car is in motion and the line switch is open, the local current set up by the generator action of one of the motors will brake the car.

The limit-switch cut-out when closed connects contacts *4* and *L* of the limit switch, independent of the action of the switch. If it is necessary temporarily to use a very heavy current, the limit-switch cut-out may be closed and the switch group operated without interference from the left-hand limit switch. The right-hand limit switch is still active. In case of excessive current during this operation, the line switch, which acts as a circuit-breaker, will open the circuit and protect the apparatus. The circuit-breaker reset switch and the limit-switch cut-out are closed only temporarily, and may be in the form of small knife switches provided with springs that will normally keep the switches open. The line-switch cut-out is normally closed during operation.

25. First and Second Positions.—On the first forward position, finger *B*+ is connected to the drum segment. On the second position, finger *5A* is active, and if the line-switch cut-out is closed, the line switch will close. At the same time, finger *2*, which in this controller is the forward reverser finger, is active, and the reverser is thrown to forward position. On the second reverse position, finger No. *1* is energized, and the reverser is thrown to reverse position. In Fig. 23, the reverser is at the forward position. Current



Type 8 Master Controller
Forward
Reverse
Forward
Reverse
C-B Reset Style B
L-S. Cut-Out Style D
Limit Switch Cut-Out Style B
Gov
Motor
Compressor
Top
Type 436-C
Train Line Receptacle
Insulation Colors in Receptacle
B+ Red
1 Red & Green
B- Black & White
5 Black
7 Green
2 Green & White
4 Red & White
Type 56-F Motors
Train Line Jumper
Type 437-A
Insulation Colors in Jumper
B+ Red B+
2 Red & Green 1
7 Green 7
5 Black 6
B- Black & White 8
1 Green & White 2
4 Red & White 4
Blow-Out Coil
Terminals
Switch
Terminals
Type 381
Line Relay
Type 301-C
Line Switch
Switch Open
Switch Closed



CAR-WIRING DIAGRAM
for
Type 251-C Switch Group
Two Motors

542 26874

from wire *2* flows through the wire R at the reverser and operates unit switch M_1; current also flows from wire R through interlocks J and M_2 and wires *14* and *15*, and operates switch JR. Switches M_1 and JR are now closed. By tracing the path through the main circuit, it will be found that both motors and all the resistance sections are in series. This is the *second*, or *switching*, *position*.

26. Third Position.—On the third position of the controller, finger *4* is energized. Current from finger *4* flows through wire *4*–interlock of the left-hand limit switch–wire L –closed interlock of switch M_1–*16*–interlock of switch J–*17* –closed interlock of switch JR–*18*–operating coil of switch S. The switch S operates and its interlock closes, thus allowing retaining current from wire R to flow through the magnet coil of switch S, and at the same time wire *20* is energized from wire *18*. Switch RR_1 now closes, and retaining current flows from wire R–interlock of switch J–*13*–magnet coil of switch RR_1. Switches R_1, RR_2, R_2, RR_3, and R_3 close in succession. Switches LS, M_1, S, JR, RR_1, R_1, RR_2, R_2, RR_3, and R_3 are now closed, and both motors are in series without resistance. This is the *series-running position*.

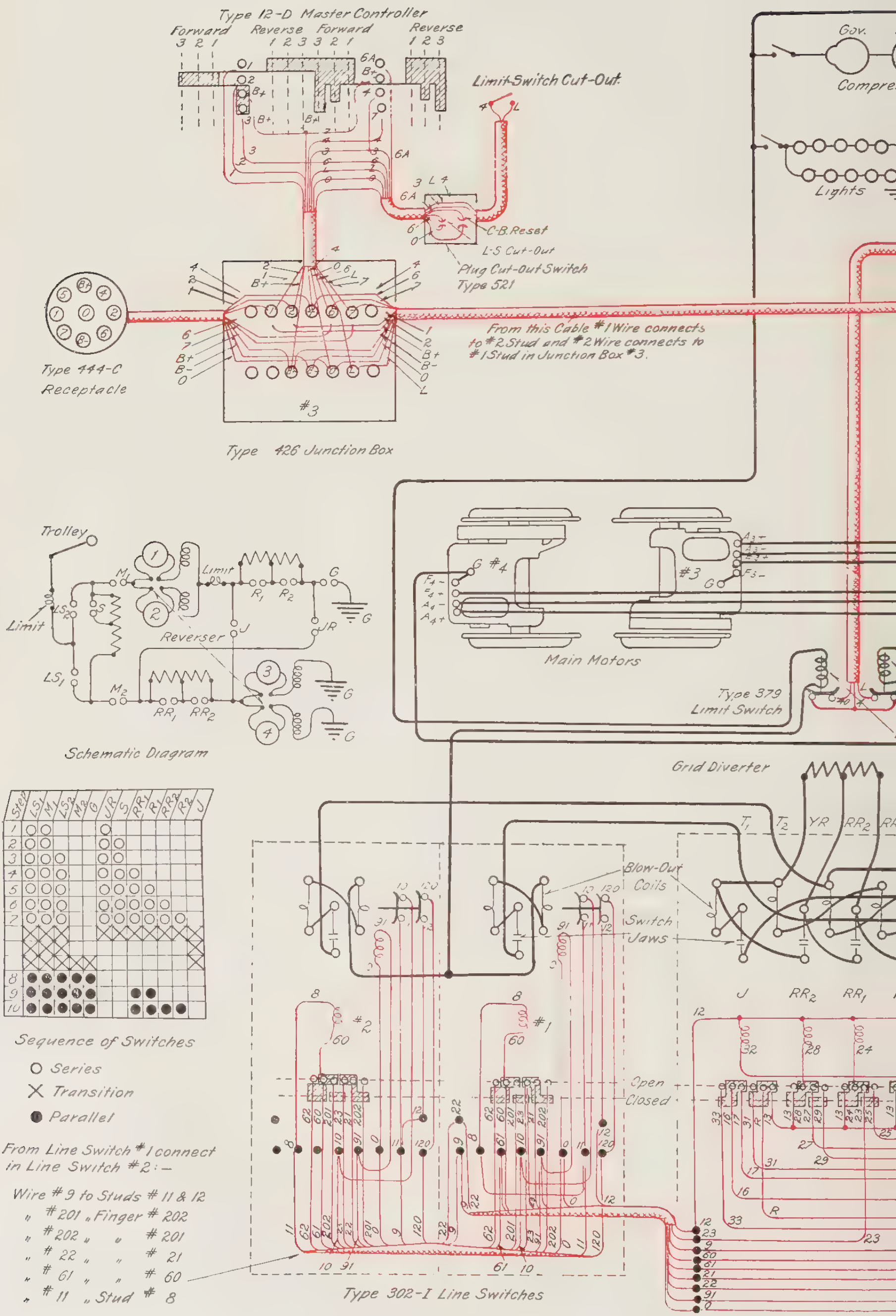
27. Fourth Position.—On the fourth position, finger 7 is active. Current flows from wire 7 to finger 7 on the motor-control cut-out–cross-connecting strip–*71*–closed interlock of switch R_3–*31*–interlock of switch G–*32*–operating coil of switch J. Switch J and its interlock close. By means of this interlock, the current from the retaining wire R is cut off from the operating coils of switches RR_3, RR_2, RR_1, R_3, R_2, R_1, and JR, as finger *13* of the interlock of switch J hangs in the air, and these switches open. The operating coil of switch JR had been receiving current through finger *13* of the interlock of switch M_2 and wires *14* and *15*. Retaining current for the operating coil of switch J is obtained from R–interlock of switch J–*31*–interlock of switch G. The motors are in series without resistance and are connected together by switch J (see schematic diagram, step *10*).

Current can now flow from the wire *L*–closed interlock of switch M_1–*16*–closed interlock of switch *J*–*33*–interlock of switch *JR*–*34*–*35*–operating coil of switch M_2, thus closing switch M_2. Finger *36* on the motor-control cut-out is energized from finger *34*, and switch *G* closes.

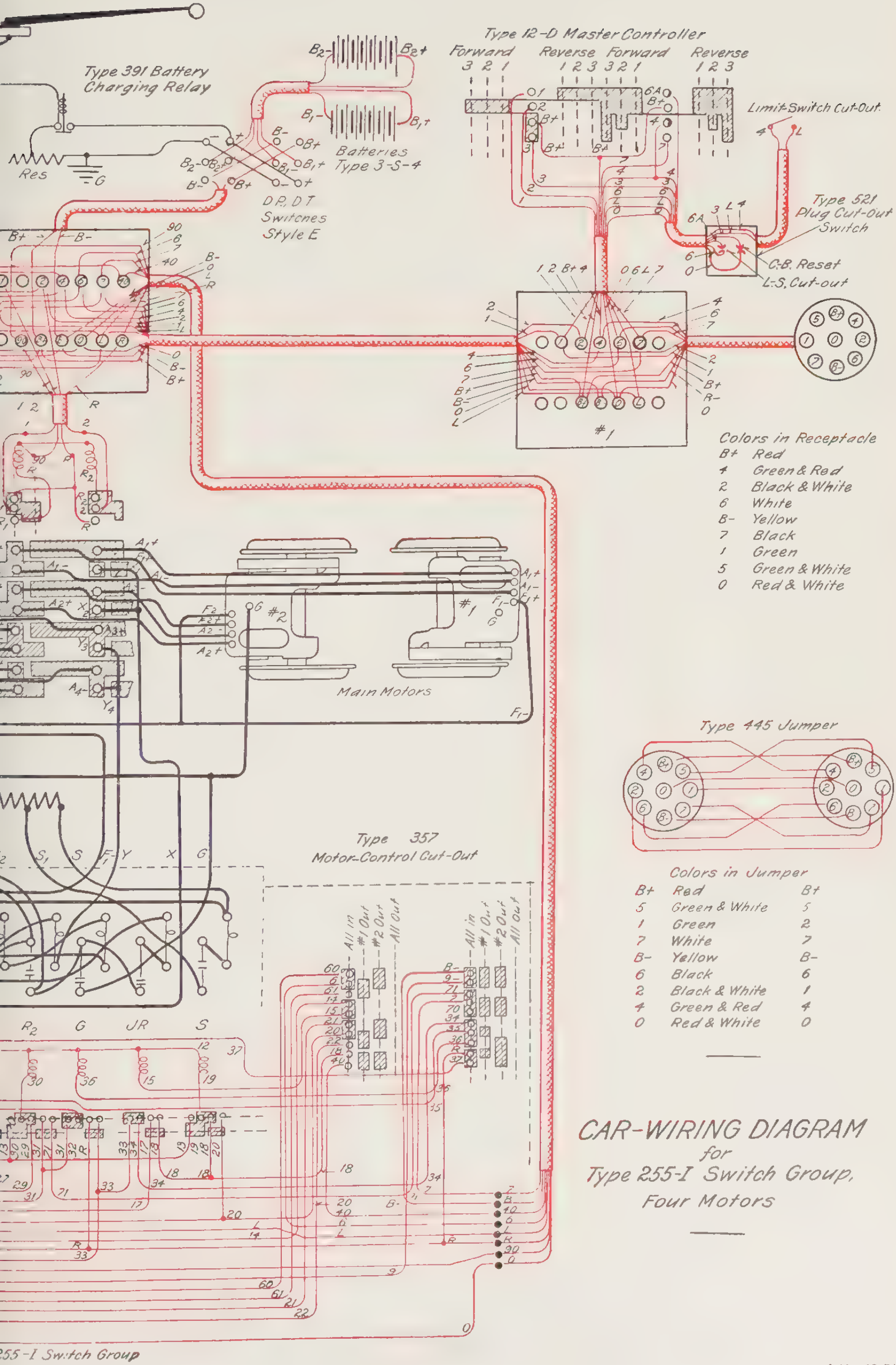
The closing of switch *G* and its interlock interrupts the retaining circuit of switch *J*; thus switch *J* opens. The motors are now in parallel with resistance sections in series with each motor. On the remaining steps, the resistance sections are cut out in the same manner as on the series position. This is the *parallel-running position.*

28. Action of Limit Switches.—The control contacts *4* and *L* on the left-hand limit switch are active in interrupting the control circuit when both motors are in circuit. The main-current coils of both limit switches are active, but control-circuit wire *40* (connected to wire *L* in the motor-control cut-out) is dead while both motors are in circuit.

When the motor-control cut-out is turned to either position *2* or *1*, finger *L* on the motor-control cut-out, which is connected to wire *40* and contact *40* on the right-hand limit switch, is active, and this limit switch now acts to interrupt the control circuit. When motor No. *2* is in and motor No. *1* out, unit switch M_1 is open, and finger *L* on the limit switch and wire *L* are dead. The open circuit is at the interlock of unit switch M_1. When motor No. *1* is in and motor No. *2* out, finger *L* and wire *L* are dead, since switches M_2 and *JR* are open. Therefore, the right-hand limit switch alone is active in interrupting the control circuit through wire *40*, finger *L* on the motor-control cut-out, and wire *18*, when only one motor is used. The right-hand limit switch may be adjusted for the conditions present when only one motor is driving the car.



Type 12-D Master Controller
Forward
3 2 1
Reverse
1 2 3
Forward
3 2 1
Reverse
1 2 3
Limit Switch Cut-Out
C-B Reset
L-S Cut-Out
Plug Cut-Out Switch
Type 521
Type 444-C
Receptacle
From this Cable #1 Wire connects to #2 Stud and #2 Wire connects to #1 Stud in Junction Box #3.
#3
Type 426 Junction Box
Gov.
Compres
Lights
Trolley
Limit
Reverser
Schematic Diagram
Main Motors
Type 379
Limit Switch
Grid Diverter
Blow-Out Coils
Switch Jaws
Open
Closed
Sequence of Switches
Series
Transition
Parallel
From Line Switch #1 connect in Line Switch #2:—
Wire #9 to Studs #11 & 12
" #201 " Finger #202
" #202 " " #201
" #22 " " #21
" #61 " " #60
" #11 " Stud #8
Type 302-I Line Switches



CAR-WIRING DIAGRAM
for
Type 255-I Switch Group,
Four Motors

SCHEDULE I

APPARATUS

29. In the system known as **schedule I**, the apparatus in general is similar to that employed in schedule F-1. The reverser and the motor-control cut-out differ slightly in details, two line switches are used instead of one, no line relay is used, and only two plug cut-out switches are employed. In case it is necessary to overload the motors for a short time, the limit-switch cut-out may be closed, thus cutting the motor limit switch out of action. The system is designed for the control of four motors of from 55 to 90 horsepower each. The principle of the action of the system is the same as in schedule F-1.

CAR-WIRING DIAGRAM

30. First Position.—In Fig. 24 is shown a car-wiring diagram for type unit-switch control, 255-I switch group, and four motors. Line switch No. *1* is closed by closing line-switch cut-out and moving the controller drum to the first position. The current path is *6A–6–60*–resetting coil of No. *1* line switch–*8–11–10–11–9–B*–. On the first forward position, finger *2*, which in this controller is the forward reverser finger, and finger *6A* are energized, the reverser is moved to forward position, and switches M_1 (wires *R* and *37*) and *JR* (wires *R–13–14–15*) are closed. Switches LS_1, M_1, and *JR* are closed, the pairs of motors are in series, and all the resistance sections are in circuit. This is the *switching position.*

31. Second Position.—Finger *4* is now active, and wire *4* and its connecting wire *L* are energized; switch *S* is thus closed. Current from wire *L* then flows as follows: Wire *L*–closed interlock of switch M_1–*16*–interlock of switch *J–17*–closed interlock of switch *JR–18–18*–closed interlock

of switch *S*–*20*–motor-control cut-out–*21*–*21*–closed interlock of No. *1* line switch–*202*–*202*–finger–*201*–*60*–operating coil of No. *2* line switch–*8*–*11*–*10*–*11*–*9*–*B*–. No. *2* line switch closes. Switch *S* and line switch No. *2* cut out sections of the resistance *S* to S_2 (see main figure and schematic diagram).

As the interlock of No. *2* line switch is closed, finger *201* of this interlock energizes finger *23*, and current flows through wire *23* and operating coil of switch RR_1, which closes switch RR_1. Switches R_1, RR_2, and R_2 close, thus cutting out the resistance sections and leaving the pairs of motors in *series-running position.*

32. Third Position.—Finger *7* is now active, and thus energizes wire *71*. The path of the current from the closed interlock of switch R_2 is: *31*–interlock of switch *G*–*32*–operating coil of switch *J*–ground. Switch *J* closes. The closing of the interlock of switch *J* opens the retaining circuit of switches RR_2, RR_1, R_1, R_2, *S*, and *JR*, and these switches open.

From wire *L* current flows to the closed interlock of switch M_1–*16*–closed interlock of switch *J*–*33*–interlock of switch *JR*–*34*–wires *35* and *36*, in parallel, and operating coils of switches M_2 and *G*, in parallel. Switches M_2 and *G* close. The closing of the interlock of switch *G* opens the retaining circuit of switch *J*, and that switch opens.

Operating current is now obtained from wire *L* through the interlocks of switches M_1, *J*, M_2–wire *20*–motor-control cut-out–wire *21*–interlocks of No. *1* line switch–*202*–*202*–finger *201*–interlock of No. *2* line switch–*23*–operating coil of switch RR_1. Switches RR_1, R_1, RR_2, and R_2 close in succession, thus cutting out the resistance sections. The switches are retained in position by current from the retaining-circuit wire *R*. The pairs of motors are now in *parallel-running position.*

The small slot in the controller drum enables the motorman to notch up, step by step, when the motors are in parallel connection, thus increasing the speed gradually.

After reaching the third position, the drum may be moved back so that the No. *4* finger hangs in the slot and the No. *4*, or limit, circuit is broken, thus stopping the progression of the switches. The drum may then be moved alternately between the slot position and the third position, and the switches notched up step by step.

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SINGLE-PHASE RAILWAY SYSTEM

THEORY OF MOTOR ACTION

INTRODUCTION

1. The application of electric propulsion to long railway lines has brought forth conditions that require a more economical and efficient system of current distribution than is possible with direct current at the usual voltage of 650 or less. The cost of copper conductors required to transmit very large currents over long distances, with a reasonable loss of power in the transmission system, prohibits their use. This has led to the development of the high-tension, alternating-current main station in conjunction with rotary-converter substations, from which direct current at a pressure of about 600 volts is supplied to the railway lines. The substation machinery is expensive, and a number of skilled attendants in each station is necessary. As the size of the car equipments increased, the current on the low-tension, direct-current circuits became excessive, and the safe limit of the carrying capacity of the trolley wire was exceeded. The third-rail system is extensively used and a large current may be carried by the conductor rail, but many engineers do not consider it advisable to place the supply conductors so near the ground, especially if high voltage is employed.

2. If a high-voltage alternating current is supplied to the trolley line and then utilized for propelling cars by means of alternating-current motors, the trolley wire may be of moderate size, even though its length is great and the car load heavy. With alternating current in the transmission lines from the main stations to the substations and in the trolley lines, the substations need contain only static transformers and auxiliary switching apparatus; that is, no moving machinery is necessary. The substation equipment is then of comparatively low cost, and little if any attendance, except regular inspection, is required.

The development of such a system was long delayed by the lack of a suitable single-phase, alternating-current motor. In 1902, however, a single-phase, series-wound commutator motor, which may be efficiently used on either alternating- or direct-current lines, as well as other apparatus necessary to make up a complete alternating-current railway system, was developed by the Westinghouse Electric and Manufacturing Company.

Polyphase induction motors are used on several roads in Europe. This necessitates two or more overhead wires. In a three-phase system, two overhead wires are sometimes used, with the rails acting as the third side of the system. Besides the complication of the overhead work, the induction motor is not well fitted for variable-speed railway work.

As the development of alternating-current railway work in the United States has been mostly along the lines of the single-phase system, this system will be described.

REVERSAL OF CURRENT

3. When an alternating current flows through the field winding and armature winding of a series motor, the polarity of the field pole pieces and the direction of the current in the armature conductors change at practically the same instant. Continuous rotation in a given direction is therefore maintained. In Fig. 1, curve *a b c* represents one cycle of an alternating current. In the portion of the cycle *a b*, the

current is assumed to flow from motor lead *d* to lead *e*, resulting in the polarity and rotation shown. At *b*, the direction of flow of current is reversed; it now flows from lead *e'* to lead *d'*, thus reversing the polarity of field poles and armature poles, but not the direction of rotation, which remains unchanged, as indicated.

In the case of an alternating-current motor, as well as of a direct-current series motor, the direction of rotation is not

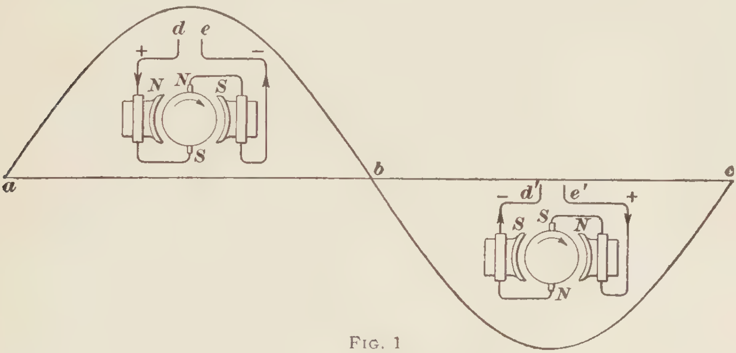


FIG. 1

reversed where *both* the field terminals and the armature terminals are reversed, but the rotation is reversed when *either* the field terminals *or else* the armature terminals are reversed.

The frame on which the field coils of the alternating-current motor are mounted, as well as the armature core, is laminated in order to prevent eddy currents, which otherwise would be set up by the alternating current in the motor windings.

SELF-INDUCTION

4. Field.—An electromotive force of self-induction is set up in the windings by the alternating current flowing through them. In the case of the main field windings, this electromotive force is reduced to its lowest value by reducing the turns of the exciting field coils to the least number capable of providing the necessary magnetic flux. The less the number of turns that are acted upon by the alternating

magnetic flux passing through them, the smaller becomes the electromotive force of self-induction.

5. Compensating Field and Armature.—The self-induction of the armature winding is practically suppressed by the action of a *compensating field winding*. This winding is frequently called an *auxiliary winding* or a *neutralizing winding*, and these terms will be used interchangeably in the following discussion. The main exciting field winding, the armature, and the compensating winding are connected in series.

In Fig. 2 is shown the development of a portion of the windings of a compensated, single-phase, alternating-current

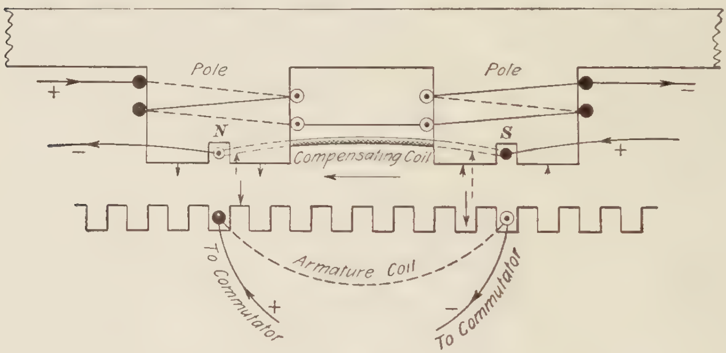


FIG. 2

series motor. The direction of motion of the armature core is indicated by the large, horizontal arrow. Only one armature coil and its corresponding compensating coil are shown. In the actual motor, there are numerous armature coils and compensating coils, the armature coils being placed in slots in the armature core, and the compensating coils, having much the same distribution, in slots in the pole faces. Two pole pieces and two main field coils are shown, as well as the resulting polarity of the poles, when the current is flowing through the field coils in the direction indicated by the arrowheads.

In order to obtain rotation in a given direction, there must be a certain relation between the polarity of the pole pieces

and the direction of current flow in the armature conductors under the poles. With the polarity as shown, and the indicated direction of rotation, the current in the armature coil flows in a counter-clockwise direction when viewed from the lower portion of the figure. The current is an alternating one, so that, while the coil is passing from contact with one brush to contact with the next, the current through the motor windings may reverse, once or more. At the instant under consideration, the current in the armature coil tends to set up a magnetic flux in the direction indicated by the full-line, vertical arrows. The compensating coil is so connected that the current flowing through it has a tendency to set up a magnetic flux in the direction indicated by the vertical, dotted arrows. These two magnetic fluxes oppose each other. If the current reverses, both magnetic fluxes are reversed in direction, and therefore still oppose each other. These fluxes practically neutralize each other in their action on the sets of coils. The self-induction in one winding is nearly neutralized by mutual induction from the other winding.

6. When a current flowing through a coil changes in value, the number of lines of force embraced by the coil also changes, and this change in the number of lines sets up an electromotive force of self-induction in the coil. If means are provided so that the first coil is subjected to the effects of induction from a second coil having an opposing magnetic flux, the coil will be practically free from self-induction, and the same value of either direct or alternating electromotive force will send about the same current through the coil. This is the effect of the action of the compensating coils on the armature coils, and the armature coils on the compensating coils. In addition to reducing the self-induction of the armature coils and compensating coils, and thereby improving the power factor of the motor, the current in the compensating winding so neutralizes the armature reaction that proper commutating conditions may be secured with fewer turns on the field winding, and thus a weaker field, than would otherwise be possible.

7. Relative Arrangements of Coils.—In Fig. 3 is shown the relative arrangement of armature, pole pieces, main field coils, and compensating coils for a four-pole motor. The main field coils are shown at *a*, *a*, *a*, *a*, and the compensating field winding at *b*, *c*, *d*, and *e*. The armature, if of large size, is usually parallel-wound and arranged for a four-pole field.

It is assumed that at a given instant the alternating current is flowing in such a direction through the main exciting field

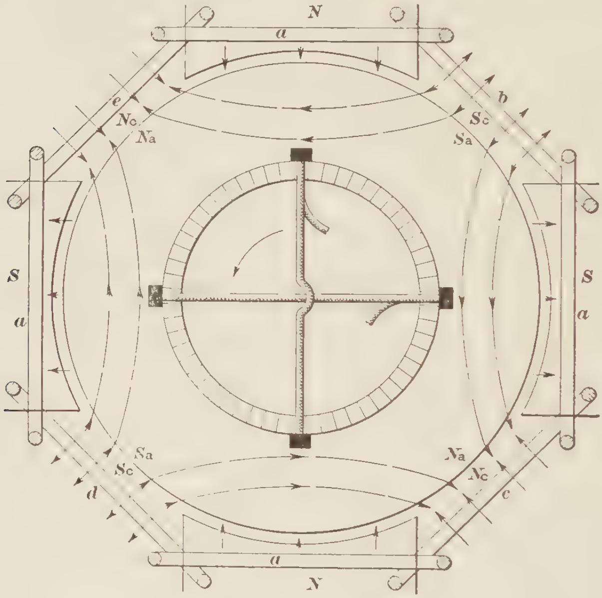


Fig. 3

coils, the armature, and the compensating coils as to tend to make the top and bottom pole pieces north poles and the side pole pieces south poles; to make two north poles N_a and two south poles S_a at the points indicated on the armature core; and to make the inner sides of compensating coils *e* and *c* north poles N_c, and the inner sides of compensating coils *b* and *d* south poles S_c. The directions of these sets of lines of force are indicated by short arrows and arrowheads.

When the current reverses, the polarities at all of these points are also reversed. As the compensating winding—here shown as four coils—in practice is distributed over the pole faces and is so connected that the current in the turns of the coils tends to set up in the pole faces and between the pole tips lines of force that directly oppose the lines of force caused by the current in the adjacent armature coils, the self-induction of the compensating winding and the armature winding is nearly, but not entirely, neutralized.

ARMATURE TRANSFORMER ACTION

8. When the armature is rotating in the magnetic field set up by the main exciting coils, a counter electromotive force is generated in the armature coils in the same manner as in a direct-current armature. There is also set up in the armature coils an electromotive force due to the alternating magnetic flux passing through the pole pieces and armature. This is practically a transformer action. The first, or mechanically generated, electromotive force is proportional to the speed; the second, or electrically generated, electromotive force is proportional to the frequency of the alternating current. The first electromotive force is the useful one, as it is the counter electromotive force of the motor. The effect of the second electromotive force in part of the coils is neutralized by the effect of the same force in the remaining coils, as illustrated in Figs. 4 and 5, so that the second electromotive force does not affect the first.

9. Ring Winding.—In Fig. 4, the polarity of the pole pieces at a given instant and the direction of rotation of the armature are assumed to be such that the counter electromotive forces generated are in the directions indicated by the full-line arrows. The directions of the counter electromotive forces are away from brushes *b* and *d* and toward brushes *a* and *c*. For convenience in representation, a ring-wound armature is shown; the coils, indicated by spirals, are all wound and connected in a similar manner.

10. The direction in which an induced current circulates around a coil depends on the direction of the lines of force

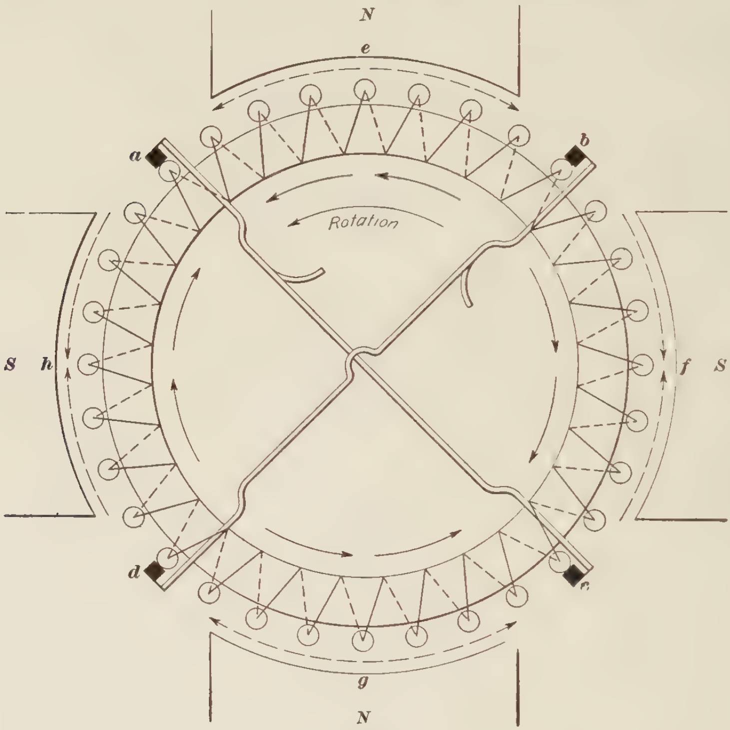


Fig. 4

in the coil and whether their number is increasing or diminishing, and may be determined by the following rule:

Rule.—*If the effect of the magnetic action is to diminish the number of lines of force that pass through the coil, the current will circulate around the coil in a clockwise direction, as viewed by a person looking along the magnetic field in the direction of the lines of force; but if the effect is to increase the number of lines of force that pass through the coil, the current will circulate around the coil in a counter-clockwise direction, as viewed by a person looking along the magnetic field in the direction of the lines of force.*

The alternating magnetic flux at a given instant is supposed to be increasing in value, and is of the polarity indicated by the letters on the pole pieces. Standing at point *e*, Fig. 4, and looking along the lines of force toward *h*, the increasing magnetic flux will set up an electromotive force that will tend to send a current around the turns of wire in a counter-clockwise direction; that is, the electrically generated electromotive force is from *e* to *h*. By similar reasoning, the electrically generated electromotive forces are found to be from *e* to *f*, from *g* to *h*, and from *g* to *f*, as indicated by the long, dotted arrows. In the set of coils between any two brushes, it should be noted that the electrically generated electromotive force in half of the coils is directly opposed by the electrically generated electromotive force in the other half of the same set of coils. These electromotive forces therefore neutralize each other, and the counter electromotive force is affected but little, if any, provided the brushes are on the neutral points.

11. Drum Winding.—In Fig. 5 is shown a developed winding of a parallel-wound, four-pole, drum armature. The field magnetic flux is assumed to be increasing in value and of the polarity shown. The directions of the counter electromotive forces are indicated by the arrowheads on the conductors. Lines of force are coming up through coil *e f* from the north pole below it. The electrically generated electromotive force, which is the result of transformer action, is in such a direction as to tend to send a current around the coil that, if it actually flowed, would set up lines of force opposite in direction to those emanating from the pole piece. The flow of current in coil *e f* would thus be clockwise, and the direction of the lines of force would be downwards through the coil. The directions of the electrically generated electromotive forces in the coils are indicated by the short arrows near the conductors.

Where a coil embraces parts of both a north pole and a south pole, the pole having the larger portion under the coil is assumed to exert the preponderant influence. For instance,

coil *g h* lies partly over a north pole, but mostly over a south pole. Lines of force are increasing in value and are passing down through the coil into the south pole. The electrically generated electromotive force is in a counter-clockwise direction, and tends to set up a current that will in turn set up lines of force passing up through the coil, these lines being opposite in direction to the main field lines passing into the

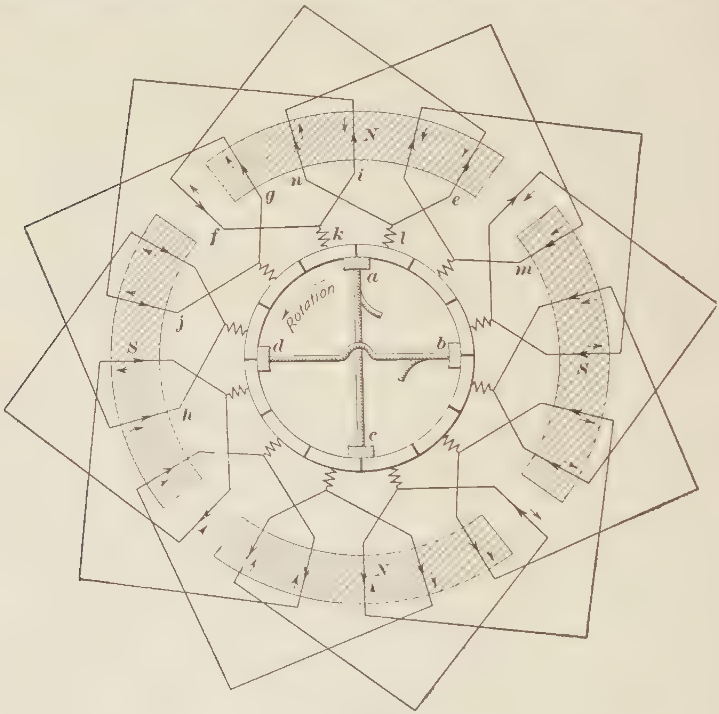


Fig. 5

south pole. It should be noted that in coils *i j* and *g h*, which are connected between brush *a* and brush *d*, the counter electromotive force is in a counter-clockwise direction in both coils, but that in coil *i j* the electrically generated electromotive force is clockwise, while in coil *g h* it is counter-clockwise. The electrically generated electromotive forces thus neutralize each other so far as their effect on the counter

electromotive force is concerned. The same conditions hold true for the other quarters of the winding.

12. Commutated Coil.—A point of importance is the effect of the alternating magnetic flux on the coils short-circuited by the brushes. In the position shown in Fig. 5, coil *e f* has its ends connected by brush *a*. The coil is over the pole piece *N*, and as the polarity of the pole piece is periodically changing, an alternating magnetic flux is set up in the coil as it moves past the pole. The coil acts as a closed secondary of a transformer, of which the field winding on the pole piece *N* is the primary. The ohmic resistance of the closed circuit is low, and a very large current would flow through the coil and thus cause violent sparking at the brushes when the local circuit is broken if precaution were not taken to prevent it. In order to reduce the short-circuited current, usually only one turn per coil is used, a low frequency of the alternating current is employed, a low value of electromotive force is applied to the motor terminals, and the magnetic circuits are carefully designed.

A method of still further reducing the short-circuited current is to connect the junctions of the coils to the commutator bars with leads of resistance metal, as shown at *k*, *l*. The resistance of the leads *k*, *l* prevents an excessive current from flowing through the local circuit composed of the coil *e f*, the leads *k*, *l*, the two commutator bars, and the brush *a*. The leads carry current only when the commutator bars to which they are connected are in contact with the brushes, as the armature windings form a closed circuit independent of the leads.

The loss occasioned by the resistance of the few leads in circuit at the brushes at any time is slight. In small alternating-current armatures, such as are used in motors for driving air compressors, no resistance leads need be used, as the brushes usually have sufficient resistance to limit the short-circuited current. In railway motors of ordinary size, the resistance leads are usually tapped to the armature winding at the rear end of the core and brought to the

commutator bars through the same slots as the main winding. In some of the large locomotive motor armatures, in order to secure a greater length, the leads are tapped to the armature winding at the front end of the core, carried to the rear end, doubled back to the front end, and then connected to the commutator. In case a short circuit should occur in the field windings or in the armature, the alternating magnetic flux would cause an excessive current to flow through the short-circuited section and perhaps cause a burn-out.

VOLTAGE RELATIONS

13. The main field coil acts as a choke coil, and has generated in it a counter electromotive force of self-induction. This introduces into the alternating-current motor a voltage that is not present in the direct-current motor and that increases the total voltage required to run the motor. As the field coil, armature, and compensating coil are in series, the voltages across the several sections of the winding may be considered as making different phase angles with the current flowing in series through the whole winding. In such a case, the total voltage would not be the numerical sum of the several voltages, as the difference in phase relation must be considered.

The total voltage may be determined by the aid of a diagram similar to Fig. 6. When two forces acting in different directions are represented by the lengths and directions of two connecting lines—the force in one line acting from its free end toward the junction of the two lines, and the force in the other line acting from the junction toward its free end—the value and direction of the resultant force are indicated by the length and the direction of the line connecting the free ends of the two lines, the direction of the resultant force being taken as opposing the general direction of the forces in the two original lines, which constitute two sides of the triangle of forces thus formed.

In Fig. 6 (*a*) is shown the motor circuit, and in (*b*), the voltage diagram. The sketches are so lettered that line *a b*

in (b) represents the voltage across the field coil $a\,b$ in (a); line $b\,c$ in (b), the voltage, under running conditions, across the armature and compensating coil $b\,c$ in (a); and line $a\,c$, the resultant, in (b), the total voltage across the motor terminals $a\,c$ in (a).

14. The directions of the current and voltages are indicated by arrowheads. The value of the current $a\,d$, Fig. 6 (b), is laid off on the horizontal line through a. As the field coil has self-induction, the field-coil voltage $a\,b$ is the resultant of two components—one component $a\,f$ necessary to overcome the counter electromotive force of self-

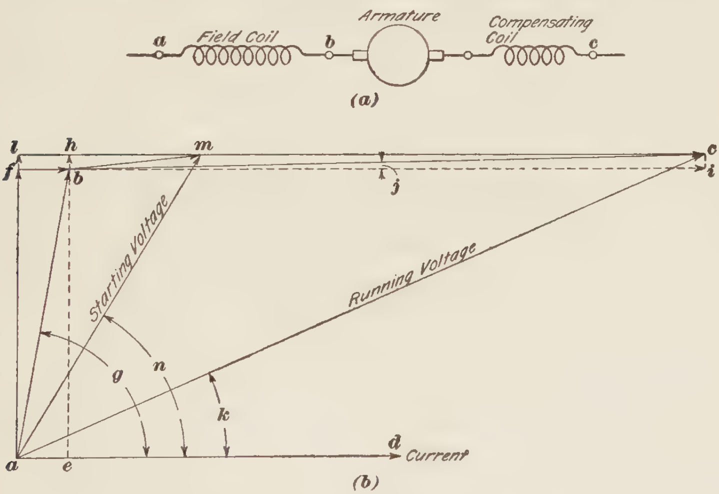


Fig. 6

induction of the coil, this voltage being 90° out of phase from the current, and the other $f\,b$, or $a\,e$, necessary to force the current against the ohmic resistance of the coil and to make up for other electrical losses, this voltage being in phase with the current. It should be noted that $f\,b$ is short in comparison with $a\,f$; therefore, the angle of lag g between the resultant electromotive force $a\,b$, applied to the field coil, and the current will be nearly 90°.

There is little self-induction in the combined armature and compensating coil, while the energy component, under

running conditions, of the applied voltage is large, since it represents, in addition to the loss in the armature and the compensating coil, due to the current flowing against their ohmic resistances, other electrical losses and the electrical energy transformed into mechanical work. The component of the applied voltage on $b c$, Fig. 6 (a), necessary to overcome self-induction is represented by the line $b h$, Fig. 6 (b), erected as a perpendicular at the end b of field-voltage line $a b$. The energy component is represented by $h c$, or $b i$, which is in phase with the current. The resultant, which represents the voltage applied to the combined armature and compensating coil, is $b c$, and since the energy component is much the larger, the applied voltage will be nearly in phase with the current, as shown by the small angle of lag j. The direction of the current is indicated by the line $b i$ parallel to $a d$.

The resultant of $a b$ and $b c$, which is the running voltage $a c$, is found by drawing a line from a to c, which are the free ends of the lines representing the electromotive forces applied to $a b$ and to $b c$, Fig. 6 (a). The direction of this voltage is from a to c, Fig. 6 (b), as indicated by the arrowhead. Considering the triangle of forces $a b c$, the general direction of the arrowheads on sides $a b$ and $b c$ is clockwise, while the arrowhead on $a c$ indicates a counter-clockwise direction. The angle of lag between the running voltage and the current is angle k. The running voltage is also the resultant of the total inductive component $a l = a f + b h$ and the total energy component $l c = f b + h c$.

15. Suppose the motor to be starting and the terminal electromotive force to be reduced so that the current through the motor windings is the same as the running current. Since the current is the same, the lines representing the electromotive forces necessary to overcome the ohmic resistance and other losses of the field coil, to overcome the counter electromotive force of self-induction in the field coil, and to overcome the counter electromotive force of self-induction in the combined armature and compensating coil,

may remain practically unchanged. These lines are fb, af, and bh, Fig. 6 (b). The energy component of the combined armature and compensating coil is now small, since the developed power at starting is inconsiderable. This component is made up of the voltage necessary to force the current through the ohmic resistance of the armature and compensating coil and to make up for the other electrical losses in these parts. At h, lay off hm equal to this energy component; the resultant bm represents the voltage across bc, Fig. 6 (a), under starting conditions. The line ab, Fig. 6 (b), remains unchanged, as the current value is assumed to be the same as under running conditions. The starting voltage am is the resultant of ab and bm, and represents approximately the electromotive force applied to the motor terminals when starting.

The angle of lag k between the running voltage and the current is much less than the angle of lag n between the starting voltage and the current. Therefore, the current in the first case is more nearly in phase with the electromotive force, and the power factor under running conditions is much higher than under starting conditions.

If the self-induction of the armature had not been neutralized by the action of the compensating coil, the power factor would have been lower under both starting and running conditions. At starting, the counter electromotive force of self-induction of the field coil has a much greater effect on the total motor voltage than under running conditions, due to the inductive component not changing greatly, while a great change takes place in the energy component. With alternating current, the starting voltage is a larger proportion of the final running voltage than when direct current is used on the same motor and under similar conditions.

16. The laminated field, the compensating winding, and the low voltage between commutator bars, which are necessary for operation on alternating current, make the performance of the motor on direct current excellent.

Owing to the lack of inductive elements and to the elimination of certain alternating-current losses, this type of motor will produce the same speed and output at a slightly lower voltage when operating with direct-current supply than when operating with alternating-current supply.

MOTORS

WESTINGHOUSE TYPE 132 MOTOR

DESCRIPTION OF MOTOR

17. In Fig. 7 is shown the exterior of a Westinghouse type 132, single-phase, alternating-current railway motor having a nominal rating of 100 horsepower. The laminated core on which the field windings are placed is built into

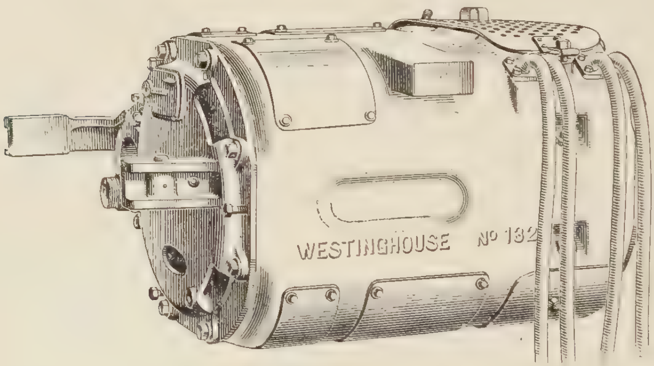


FIG. 7

the cast-steel outer frame that holds the core in position. The end brackets are fitted on machined seats and support the armature bearings. The frame is of the box type. The armature may be removed by taking off the pinion and the brackets. To give access to the brushes and brush holders, openings are provided in the frame, both above and below the commutator.

The laminated field core is so constructed as to form four projecting pole pieces, on which the four main field coils are placed. The faces of these pole pieces contain slots, in

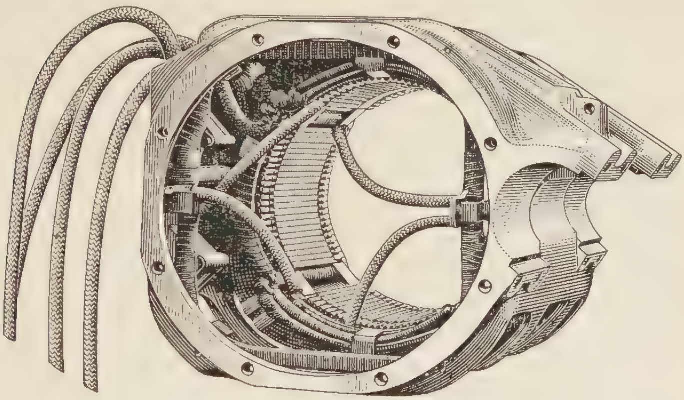


FIG. 8

which are placed the conductors constituting the compensating field winding, as shown in Fig. 8. The main field coils consist of a few turns of heavy copper strap, and are

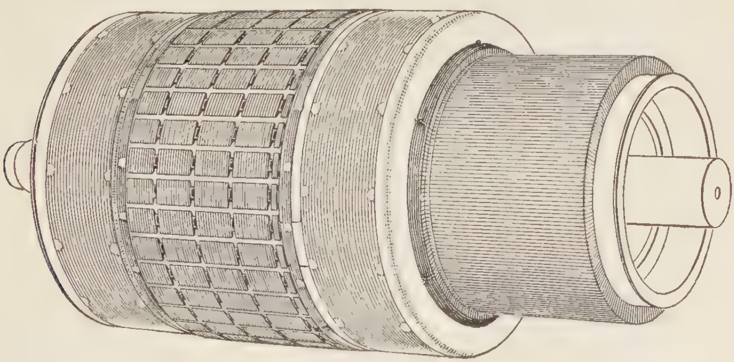


FIG. 9

mounted on the short, projecting pole pieces. The compensating, or neutralizing, coils, consisting of copper bars connected at the ends by copper straps so as to form a

continuous winding, are distributed in a number of slots in the pole pieces, in order to obtain a distribution similar to that of the armature conductors.

The action of the current in the conductors of the compensating coils neutralizes the self-induction of the adjacent

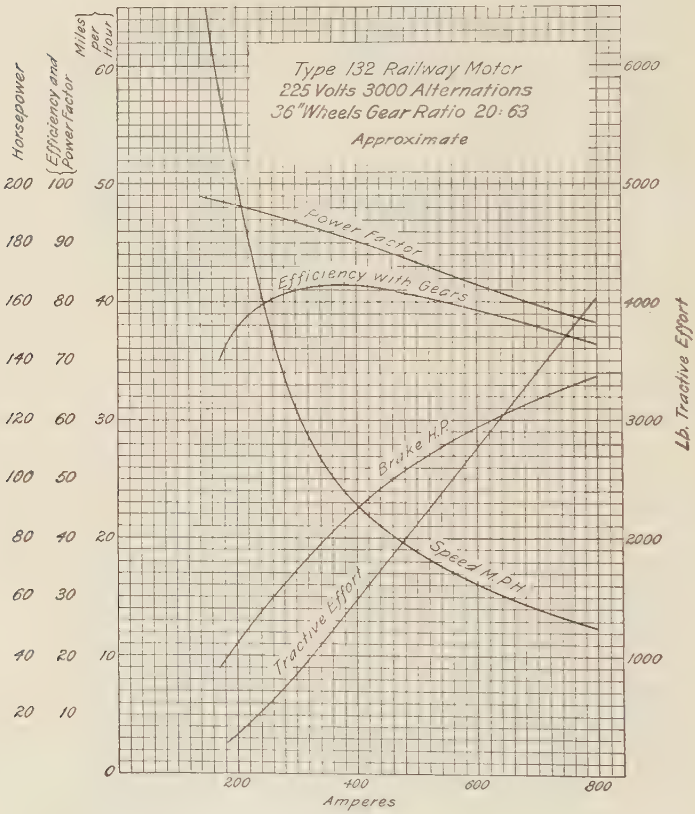


FIG. 10

armature conductors. As there is mutual induction between the compensating winding and the armature winding, the self-induction of the compensating coils is also reduced. The main field winding is thus the source of most of the electromotive force of self-induction of the motor winding.

Fig. 9 shows the armature for the type 132 motor. Resistance leads are used to connect the back end of the armature coils to the commutator bars, and thus prevent an excessive current from flowing in the coil short-circuited by a brush. The armature is parallel-wound and has four sets of brushes.

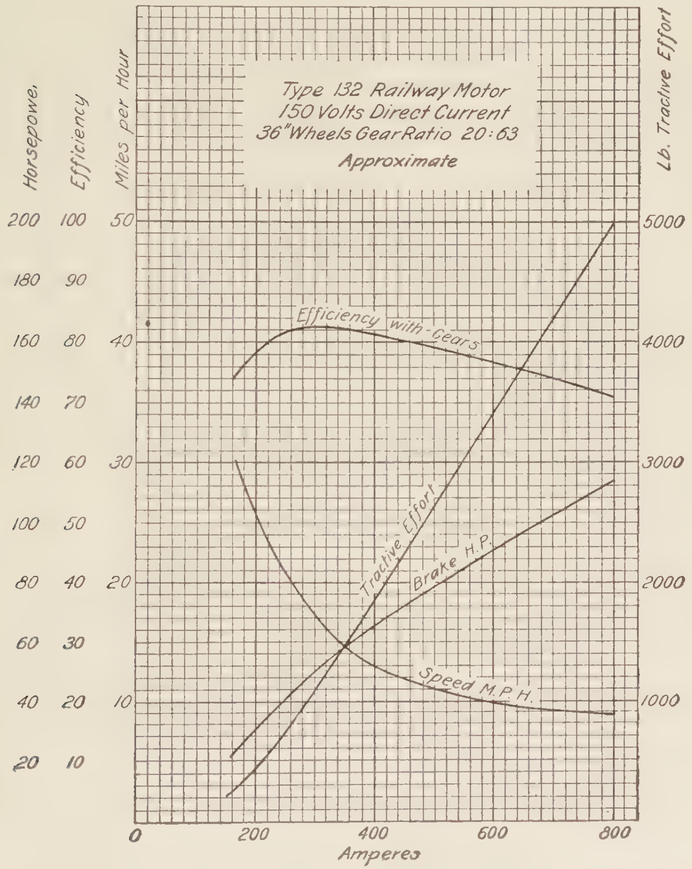


FIG. 11

The main field coils, the armature, and the compensating field coils are connected in series. The motors are ordinarily wound for a potential of 250 volts. The frequency of the alternating current is usually 25 cycles.

PERFORMANCE CURVES

18. In Fig. 10 is shown a performance curve for a type 132 Westinghouse motor operating on 225 volts, single-phase alternating current. Fig. 11 shows a performance curve for the same type of motor operating on 150 volts, direct current. Four motors are in series on a 600-volt, direct-current circuit, and the speed is comparatively low, being suitable for city traffic. In order to use curves of this kind, proceed as follows: It is desired to find the tractive effort, Fig. 10, when the motor is taking a current of 460 amperes. Each small space on the base line *0–800* represents 20 amperes; therefore, the 460-ampere line is $460 \div 20 = 23$ lines from the point *0*, or 3 lines to the right of the point *400*. The 460-ampere line cuts the tractive-effort curve at a point about $18\frac{1}{2}$ spaces above the base line. As each space equals 100 pounds of tractive effort, as shown by the line of values on the right-hand margin, $18\frac{1}{2}$ spaces equal 1,850 pounds. With the same current flow, the speed in miles per hour is 20, as shown by the line of values of miles per hour. The brake horsepower is 100; the efficiency with gears, nearly 82 per cent.; and the power factor, .88.

By selecting a certain point on one curve, corresponding values on the other curves may be found by determining where a vertical line through the selected point cuts the other curves and then reading the values of these points by means of the data lines on the margins. For example, in Fig. 10, the point of highest efficiency is on the 360-ampere line; under these conditions the horsepower is 82, and the tractive effort about 1,200 pounds.

LOCOMOTIVE TYPE MOTOR

19. Powerful single-phase, alternating-current motors have been constructed by the Westinghouse Company for the electric locomotives used by the New York, New Haven, and Hartford Railroad Company. The motors are of the gearless type, and are suitable for use on either a direct- or an

alternating-current system. In electrical design, the motors are of the same general type as those used for interurban service. There are four motors on each locomotive, one motor being connected to each pair of wheels.

The armature, Fig. 12, is not placed directly on a shaft, but is built up on a hollow cylinder, or quill, through which the car axle passes. There is a clearance of about $\frac{5}{8}$ inch between the axle and the inside of the quill. The motor frame rests on bearings located near the rear of the armature core and the front end of the commutator shell. At each end of the quill is a flange, from which project seven round, hollow pins, as shown. These pins fit into corresponding

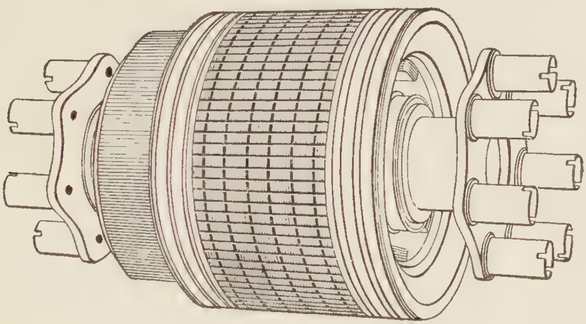


FIG. 12

pockets in the hubs of the wheels, as shown in Fig. 13. Between bushings on the driving pins and bushings in the pockets are placed coiled springs that take up the vibrations of the truck. The spring wound on the bushing of each driving pin is so constructed that it holds the pin nearly central in the recess. The end play of the motor is taken up by coiled springs within the hollow driving pins. These springs press against covers in the outer ends of the spring pocket in the wheels. Fig. 13 shows the relative positions of a motor and its driving wheels.

The entire weight of the motor is normally carried on springs supported from a steel frame surrounding the motor and resting on journal-boxes on the truck frame. Each motor

has a normal rating of 250 horsepower and a continuous capacity of 200 horsepower, or a total of 800 horsepower per locomotive. The motors are wound for a normal full-load speed of about 225 revolutions per minute. The four motors are connected permanently in pairs, each pair being composed of two motors in series.

An alternating-current voltage of about 450 volts, or a direct-current voltage of from 550 to 600 volts, is applied to

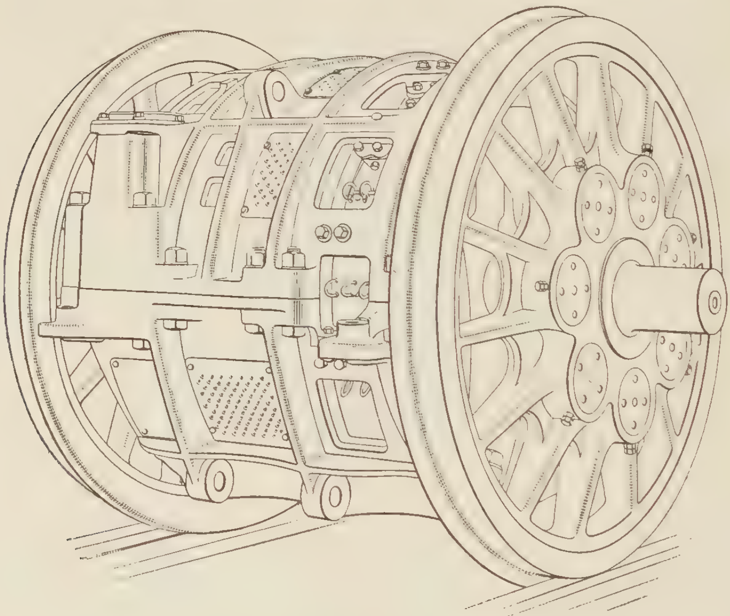


Fig. 13

the terminals of the group of motors. In direct-current operation, the pairs of motors are first connected in series, and then in parallel. In alternating-current operation, two electrically and mechanically distinct autotransformers—one for each pair of motors—are used. The secondary electromotive forces are impressed across the terminals of the pairs of motors.

GENERAL ELECTRIC GEA-605-A MOTOR

DESCRIPTION OF MOTOR

20. In Fig. 14 is shown a type of single-phase, alternating-current motor manufactured by the General Electric Company. The motor is rated at 75 horsepower, and may

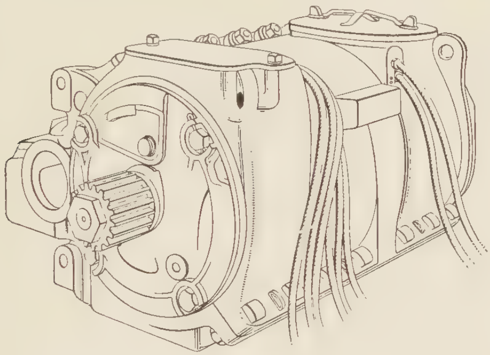


FIG. 14

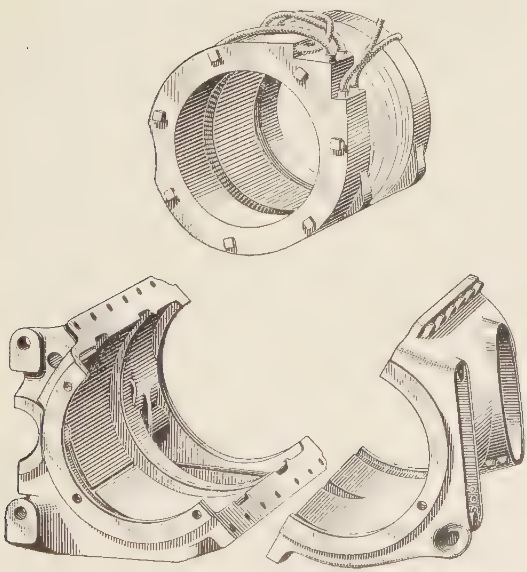


FIG. 15

be operated on either alternating or direct current. The core on which the field windings are placed is laminated, and is held in position by the outer steel casting forming the structural frame of the motor. The housing and the inner laminated ring of the motor are shown in Fig. 15. The field windings are in two sections; namely, the exciting winding

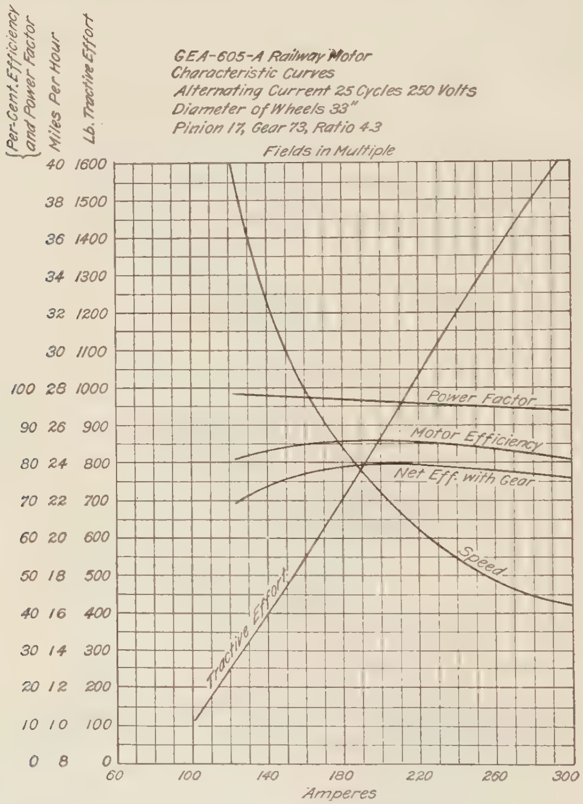


Fig. 16

mounted on short poles formed in the laminated core, and the compensating winding placed in slots in the pole faces. The field windings and the armature are connected in series.

The armature has a series-drum winding similar to a direct-current winding, but as the current taken by the motor

is large, four sets of brush holders, each set containing four brushes, are provided. The motors are designed for an electromotive force across their terminals of about 250 volts.

PERFORMANCE CURVES

21. In Fig. 16 is shown a performance curve of a GEA-605-A motor operating on 250 volts, alternating current. Fig. 17 shows the performance curve of the same

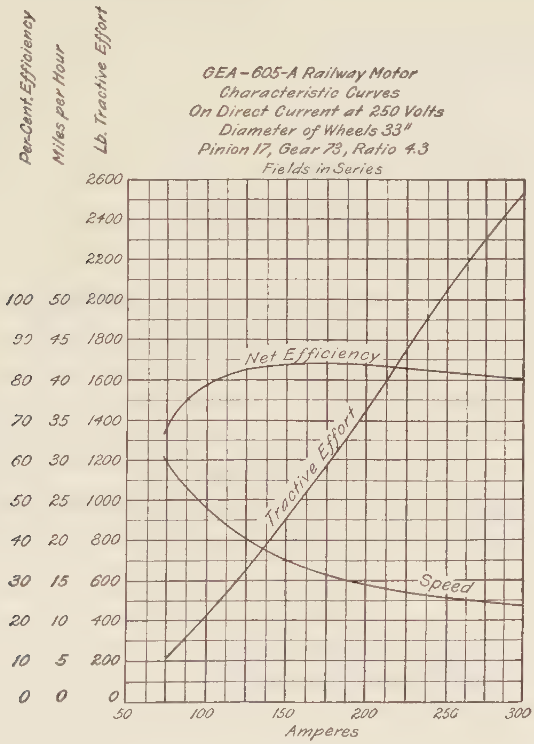


FIG. 17

type of motor operating on 250 volts, direct current. In these curves, the alternating-current voltage and the direct-current voltage are the same. When operating with alternating current, the highest net efficiency is 80 per cent., and when operating with direct current, 83.5 per cent.

THE AUTOTRANSFORMER

22. The voltage used on the trolley wire of single-phase roads has not been limited to a single standard value, as with direct current, but is usually 3,300, 6,600, or 11,000. The motors are generally wound for a voltage of from 225 to 250, and the trolley voltage is reduced for use at the motors by means of an **autotransformer**, or a *compensator*, as it is also called, mounted on the car.

The autotransformer has one coil only, a portion of it serving the purpose of both a primary and a secondary winding. The coil is wound on a laminated-iron core, and taps are brought out at intervals, the primary and secondary circuits being connected to these taps.

23. The connections of an autotransformer arranged for a high-voltage primary and a low-voltage secondary are shown in Fig. 18. Terminal *a* is connected to the high-ten-

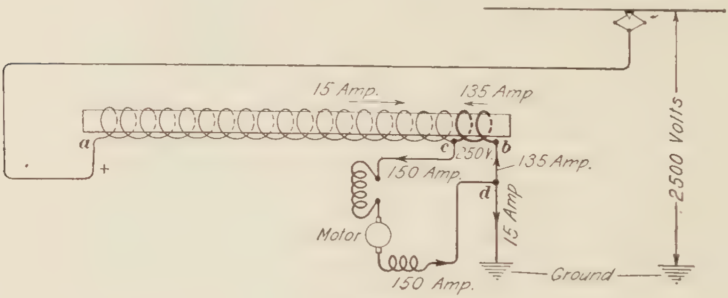


Fig. 18

sion trolley wire, and terminal *b* is connected to the ground. The secondary lines *c b* are connected across a section of the coil. The whole coil *a b* acts as a primary coil, and, in addition, the section *c b* of the primary acts as a secondary coil.

With a given primary electromotive force, the secondary electromotive force is directly proportional to the ratio of the

number of secondary turns to the number of primary turns. For example, if the primary electromotive force is 2,500 volts, the secondary turns 2, and the primary turns 20, the secondary electromotive force is $2{,}500 \times \frac{2}{20} = 250$ volts. In an actual autotransformer for high voltage, the number of turns would be much greater than the number indicated in Fig. 18.

24. A motor requiring 150 amperes at 250 volts is connected to the secondary lines. The electromotive force of the primary circuit being ten times that of the secondary circuit, the current in the primary circuit, neglecting the transformation losses, is approximately one-tenth of that in the secondary circuit, or 15 amperes. The end *a* of the coil is assumed to be positive at a given instant. Point *c* is at a higher potential than *b*; therefore, current will flow from *c*, through the motor, and back to the coil at *b*. The 150 amperes flowing from *c* to the motor is made up of the 15-ampere primary current flowing in from the line to terminal *a* and 135 amperes from the secondary coil that is forced to flow from *b* to *c* by the electromotive force generated in the secondary coil. Not all of the motor current is a transformed current; part of it is primary current. The autotransformer, therefore, for a given output, may be smaller than the ordinary two-coil transformer where the secondary current is entirely a transformed current. The current of 150 amperes flowing from the motor divides at *d*, 135 amperes flowing to *b* and through the secondary coil from *b* to *c*, and 15 amperes—the primary current—flowing from *d* to the ground.

The current in the secondary coil is the difference between the current in the primary lines and that in the secondary lines. The current in section *a c* of the primary coil flows in a direction opposite to that in the secondary coil. The electromotive force applied to the secondary circuit may be varied by connecting the secondary terminals to different points on the primary winding. The portion of the coil that is used for a secondary is constructed of much larger wire than the rest of the coil, as it must carry, in the case of a

step-down autotransformer, a much larger current. If the autotransformer shown in Fig. 18 were to be used as a step-up transformer, the primary lines would have to be connected to *c b* and the secondary lines to *a b*.

25. In Fig. 19 is shown an oil-insulated, self-cooling autotransformer for use in connection with single-phase,

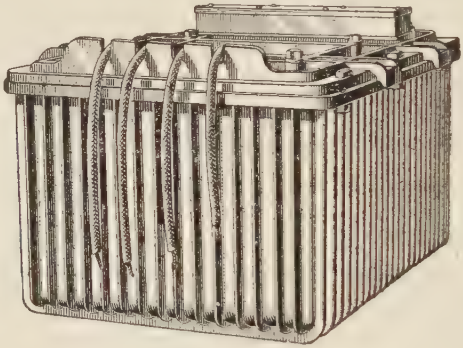


FIG. 19

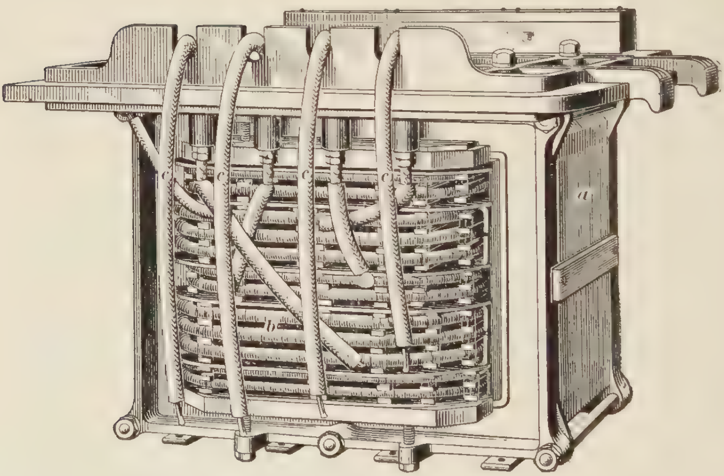


FIG. 20

alternating-current railway equipment. Fig. 20 illustrates the interior of the autotransformer. At *a* is shown a portion of the laminated shell core; at *b*, the coils; and at *c*, the leads.

CAR CONTROL

26. Speed control of the single-phase railway motor is obtained by varying the voltage at its terminals, the same as with direct-current motors. Where alternating current is used, however, this can be done much more easily and economically than with direct current. Instead of first connecting the motors in series and then in parallel and using a variable resistance in the circuit with each grouping, as is done with direct-current motors, it is merely necessary to connect the alternating-current motors to different steps on the autotransformer. This is accomplished in small equipments, where single-car operation only is desired, by means of drum-type controllers that are similar in general appearance to those used with direct-current motors. In large equipments, or where multiple-unit train operation is desired, essentially the same connections are made by means of unit switches operated by compressed air from the air-brake system and controlled by electromagnetic valves, or by means of electrically operated switches controlled directly from the master controller. The action of the magnet valves is regulated by a master controller, and current for operating them is supplied by a small 14-volt storage battery on the car.

Whenever a car equipment consists of only two motors, they are permanently connected in parallel, so that in case of damage to either motor, it may be cut out of circuit without interfering with the operation of the other. Where the equipment consists of four motors, however, they are connected two in series, and these two groups are connected in parallel. In case of damage to one motor of a four-motor equipment, the pair of motors to which it belongs is cut out. This arrangement is used to reduce the cost of controllers, switches, wiring, etc., which, within the limits ordinarily used, depends on the current to be handled rather than on the voltage. Thus, the same controller or switch group is

used with a given size of motor, whether the equipment consists of two or four motors.

27. On some roads it is necessary to operate on direct current as well as on alternating current. The direct-current operation is generally through cities or towns, where the speed is necessarily limited, while the alternating-current operation is in the open country, where a high speed is usually desirable. The single-phase motor will operate somewhat faster on direct current than it will on alternating current of the same voltage. If, therefore, two 250-volt,

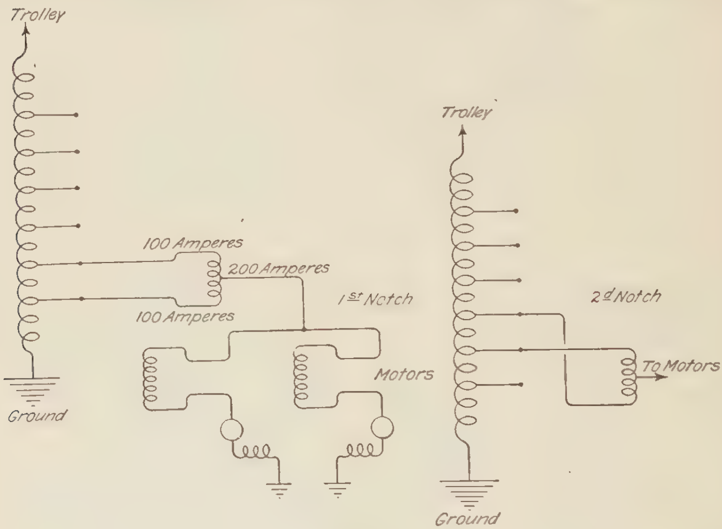


FIG. 21

alternating-current motors are geared for the proper alternating-current speed, are then operated in series from a 500-volt, direct-current trolley system, the speed under these circumstances will usually be very much higher than is required. On this account, equipments for operation on both alternating and direct current are usually provided with four motors. These motors are operated two in series in the ordinary way on alternating current, but are connected all four in series on direct current. With this arrangement the

speed of a car with normal direct-current voltage on the trolley is about two-thirds of that with normal alternating-current voltage. When operating on direct current, the motors are controlled in the ordinary way by means of a resistance in series with them.

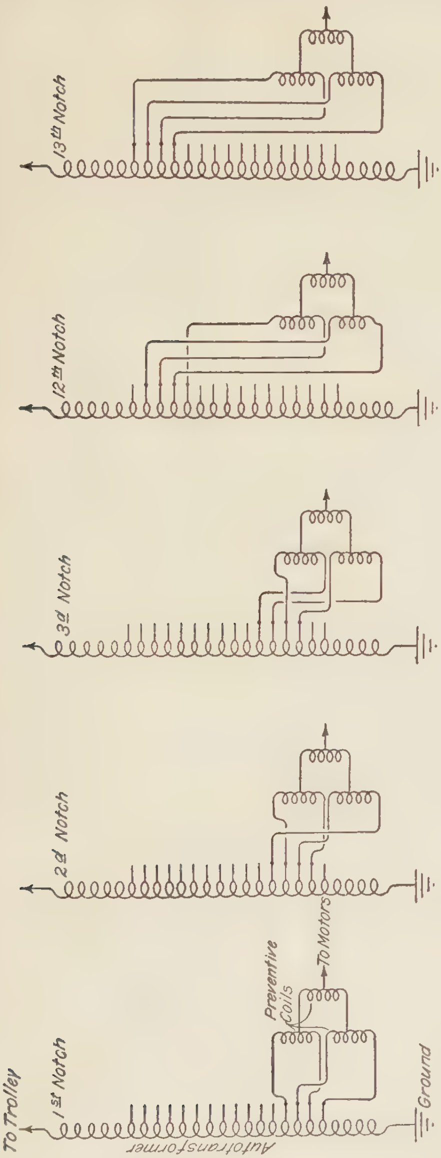


FIG. 22

28. In connecting the motors to the autotransformer, use is ordinarily made of one or more *preventive-reactance coils*, for dividing the current between two or more switches, or contacts. Thus, in Fig. 21, six taps and contacts, each of which is capable of carrying 100 amperes, will do the same work and provide for the same number of running points that would require five taps and contacts of double that size if the preventive coil were not used. In Fig. 22, sixteen taps and contacts, each of which

is capable of carrying 100 amperes, will do the same work that would otherwise require thirteen contacts of four times this capacity.

In addition to dividing the load among a number of small contacts, the use of the preventive-reactance coils serves also to prevent the necessity of opening the motor circuit when passing from one controller notch to the next, since in making this change only one lead is disconnected at a time. The two leads of a coil are so advanced that the former bottom lead becomes the upper lead as the coil is connected to the next higher-speed point. The reverse of this action takes place when the coil is connected to the next lower-speed point, as indicated in Figs. 21 and 22.

29. For use in connection with drum-type controllers, a *preventive resistance* is connected in parallel with the preventive-reactance coil, to reduce the sparking that may occur when breaking a tap contact. This arrangement of resistance and reactance coils is shown in connection with the following explanation of the type 224 controller. Each half of the preventive-reactance coil is bridged by one-half of the resistance. When one of the tap contacts is broken, the current suddenly decreases in one-half of the reactance coil. This would set up a high electromotive force of self-induction, and might cause sparking at the contact, if it were not for the portion of the resistance through which the reactance coil may discharge and thus allow the current and the magnetic field to decrease in strength slowly. In general, the action of this resistance is the same as that of the field discharge resistance ordinarily used in opening the field circuit of generators. The preventive resistance is so proportioned that there is very little loss in it, and in order to simplify the controller connections, it is left in circuit all of the time, except on the last notch, where it can be cut out without adding complication. On account of the greater breaking capacity of unit switches, this resistance is not required where they are employed.

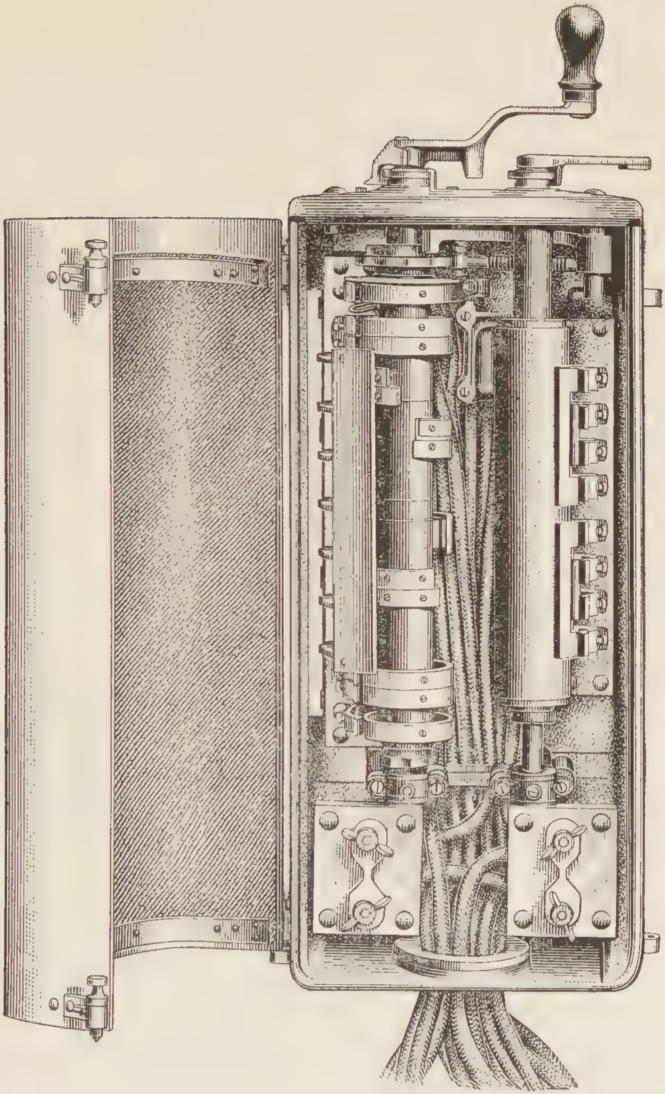


FIG. 23

TYPE 224 WESTINGHOUSE CONTROLLER

DESCRIPTION OF CONTROLLER

30. In Fig. 23 is shown a **type 224 Westinghouse controller** suitable for hand operation with two or four 50-horsepower, single-phase, alternating-current motors. In general appearance this controller is similar to a controller for direct-current operation. It contains a main power drum for connecting the various autotransformer taps to the motor circuit, and a reverse drum for reversing the direction of rotation of the motor armatures. Fig. 24 shows the preventive-reactance coil, and Fig. 25, the preventive resistance, used in connection with the type 224 controller.

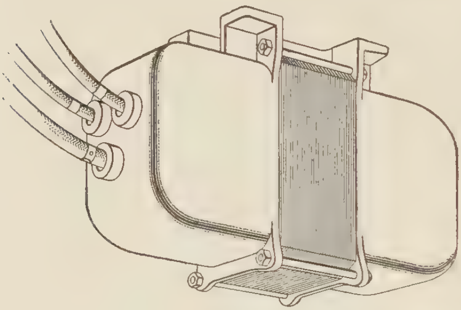


FIG. 24

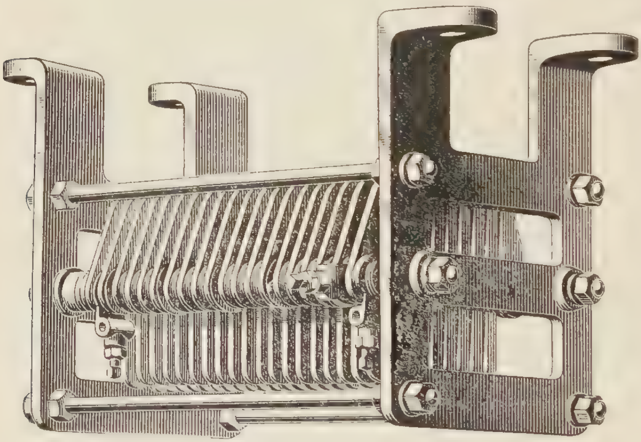


FIG. 25

CONTROLLER-WIRING DIAGRAM

31. In Fig. 26 is shown an autotransformer with six secondary taps and the wiring diagram of a type 224 hand controller arranged for connecting the several autotransformer taps to the motor circuit. The taps provide effective electromotive forces of 160, 190, 220, 250, 280, and 310 volts. The electromotive forces impressed on the motor terminals differ slightly from these values, due to the action of the preventive coils.

The motor circuits receive current from the middle points of the preventive-reactance coil and the preventive resistance,

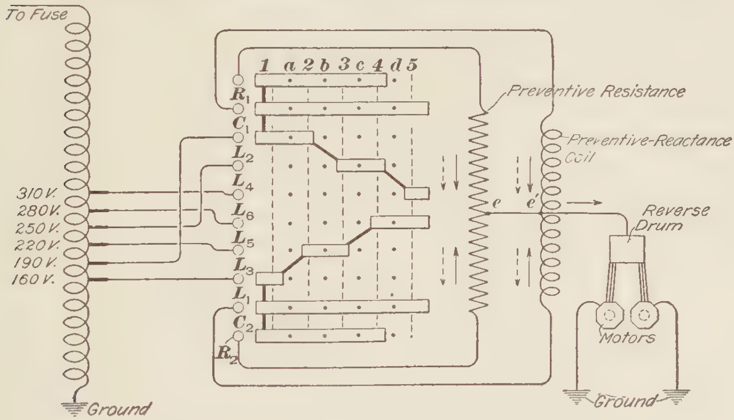


FIG. 26

across which an electromotive force of 30 volts is impressed. The connections of the autotransformer, the preventive resistance, the preventive-reactance coil, the reverse drum, and the motors are shown diagrammatically in Fig. 27 for the five running notches. When the controller, Fig. 26, is on the *first notch*, as indicated by the dotted line under *1*, near the top of the controller, fingers R_1 and C_1 are connected with L_2 (the 190-volt tap), and fingers C_2 and R_2 are connected with L_1 (the 160-volt tap). As R_1 and R_2 are the terminals of the preventive resistance, and C_1 and C_2 are the terminals of the preventive-reactance coil, the electromotive force impressed on the coils is 190 volts − 160 volts

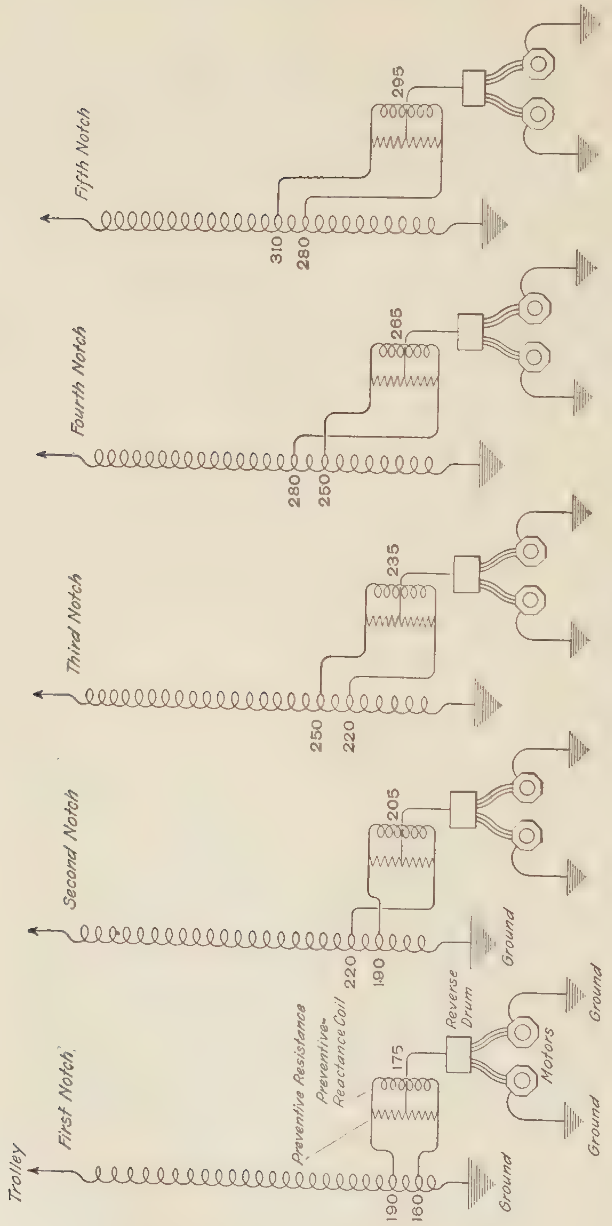

Trolley
First Notch
190
160
Ground
Preventive Resistance
Preventive-Reactance Coil
175
Reverse Drum
Motors
Ground
Ground
Second Notch
220
190
Ground
205
Third Notch
250
220
235
Fourth Notch
280
250
265
Fifth Notch
310
280
295

FIG. 27

= 30 volts, and the electromotive force at the middle points e and e' of the coils is 15 volts higher than the lower value and 15 volts lower than the higher value, or 175 volts. The electromotive force of 30 volts forces currents through the resistance and the reactance coil independent of the operation of the motors. The directions of these currents are from the tap that is at a given instant of a higher potential to the tap that, at the same instant, is of a lower potential. The current therefore alternates through the coils.

32. First Notch.—If, in Fig. 26, the trolley wire is positive at a certain instant and the controller is on notch *1*, L_2 is at a higher potential than L_1, and the electromotive force of 30 volts tends to send currents through the preventive coils in the directions indicated by the dotted arrows. If the motor circuit is also active, the currents from L_2 and L_1 flow to e and e' through the coils in the direction indicated by the full-line arrows. The motor currents in each half of a coil are in opposite directions and of nearly equal value. The currents join and flow to the motor circuit at the middle point of the coils. Where the normal exciting current of a coil and the motor current oppose each other, the motor current predominates and determines the direction of flow. At the particular instant under discussion, motor currents flow from the 190-volt tap L_2 to e and e', and from the 160-volt tap L_1 to e and e', there being an electromotive force of approximately 175 volts impressed on the motor circuit.

33. Second Notch.—When the controller is passing from the first to the second notch, finger L_1 drops contact with its drum segment, while finger L_2 still remains in contact with its drum segment. Current then flows through the upper portions only of the preventive coils and to the motor circuit from the 190-volt tap. The intermediate positions of the fingers are indicated by the dots under the letters a, b, c, and d. On the second notch, R_2 and C_2 are connected with L_3 (the 220-volt tap), and R_1 and C_1 are still connected with L_2 (the 190-volt tap). The impressed electromotive force on the motor circuit is now 205 volts.

At the intermediate position b, L_3 remains in contact with its drum segment, but L_2 drops contact with its segment. Therefore, current flows from the 220-volt tap only.

34. Third Notch.—On notch *3*, taps L_4 and L_3 are active, and the electromotive force impressed on the motor circuit is 235 volts. At the intermediate position c, L_4 remains in contact with its drum segment, but L_3 drops contact with its segment. Current now flows from the 250-volt tap only.

35. Fourth Notch.—On notch *4*, taps L_5 and L_4 are in service, and the electromotive force impressed on the motor circuit is 265 volts.

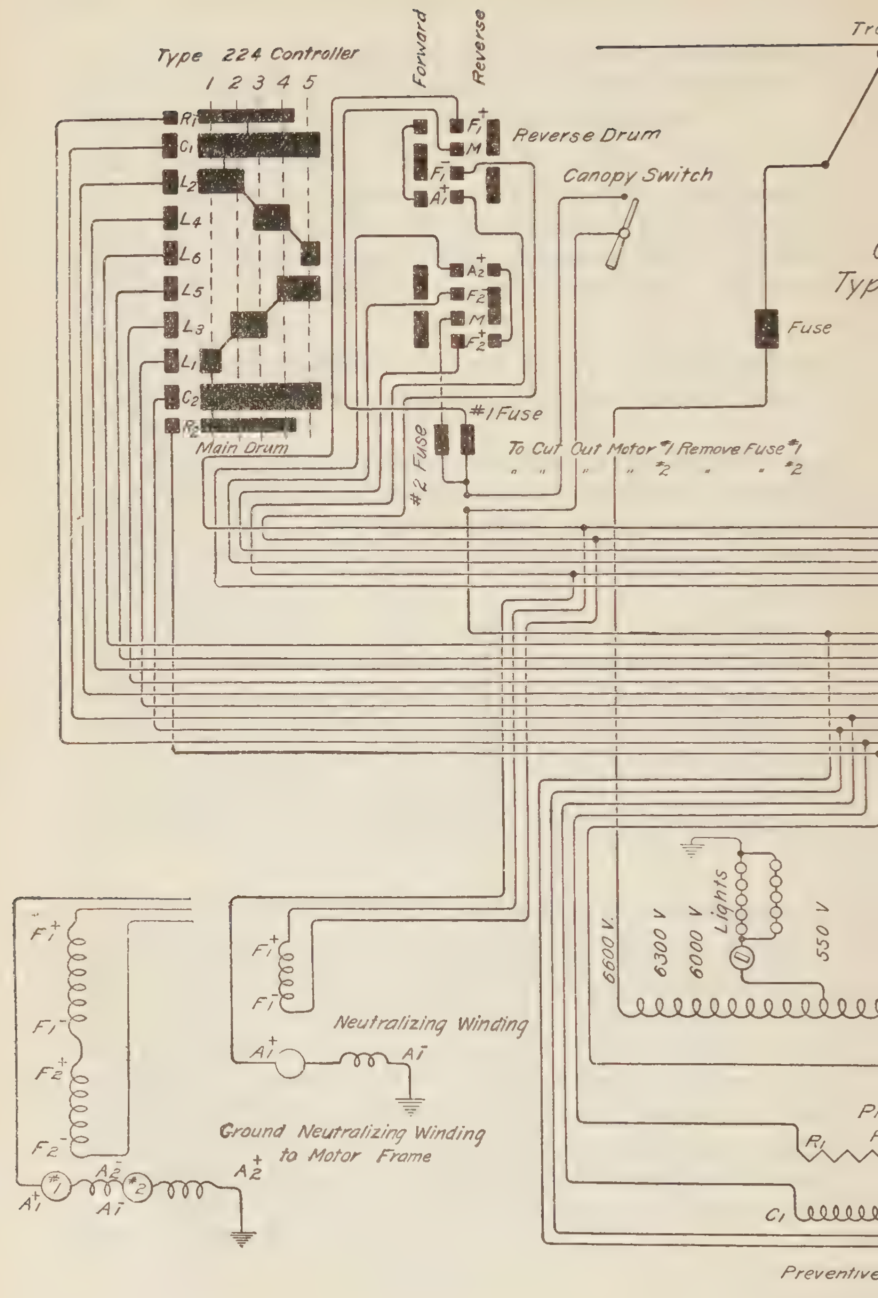
As R_1 and R_2 drop contacts with their drum segments at intermediate position d, the preventive resistance is cut out of circuit. Tap L_5 and the lower half of the reactance coil are alone active at this point, and current now flows from the 280-volt tap to the motors.

36. Fifth Notch.—At the final notch *5*, taps L_6 and L_5 are active, and both sections of the reactance coil carry currents to e' and to the motor circuit. The final electromotive force impressed on the motor circuit is 295 volts.

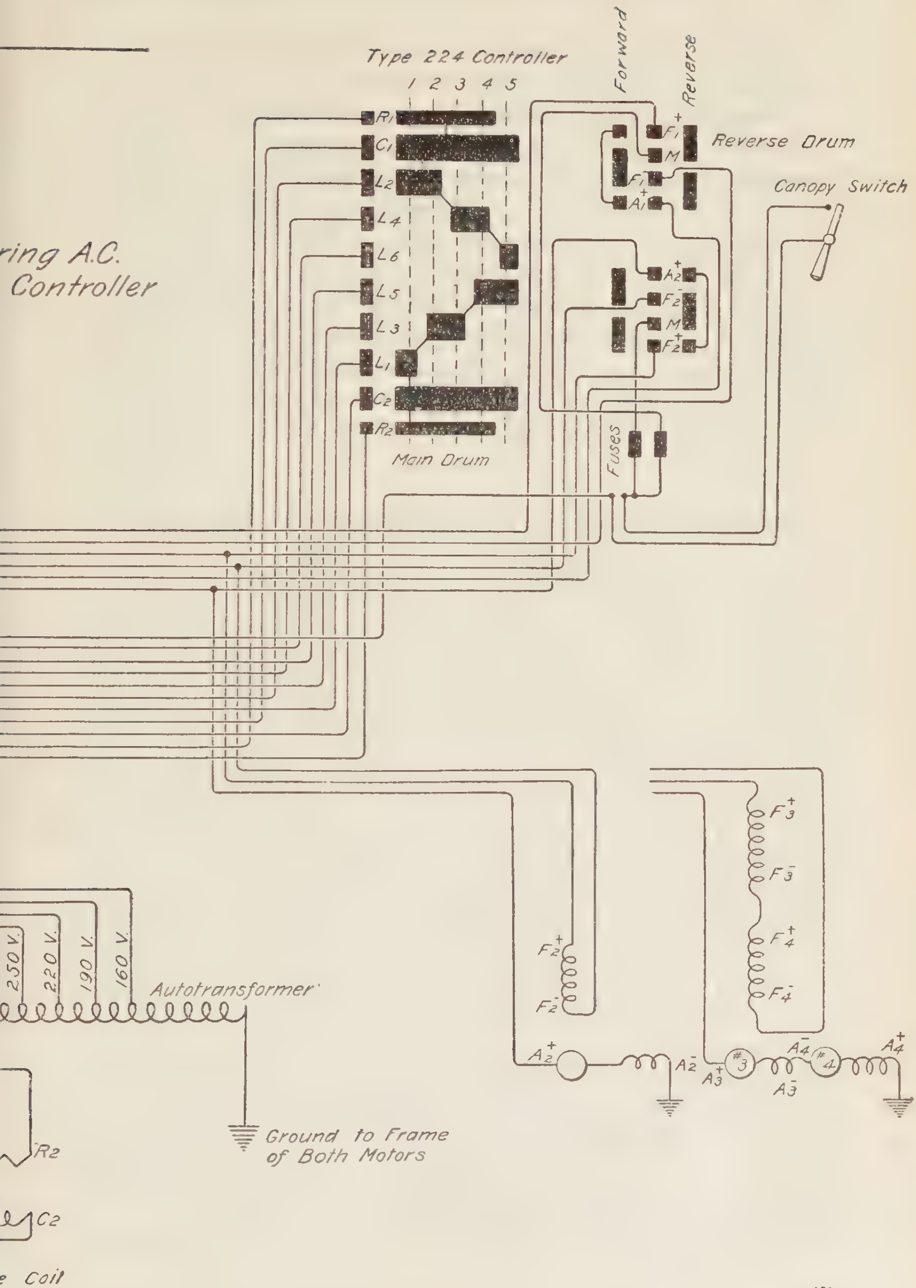
In Fig. 27 is indicated the voltage of the taps and the motor circuit for the five controller notches. All of these notches may be used efficiently for running, if so desired.

TYPE 224 CONTROLLER CAR-WIRING DIAGRAM

37. In Fig. 28 is shown a car-wiring diagram for two Westinghouse type 224 controllers suitable for the operation of two or four type 108, single-phase, 50-horsepower motors. The operation of the main controller drum has just been explained. The wire from the middle of the preventive coils leads to a car wire that connects to two fingers marked M on the reverse drum of each controller. The two motors are permanently connected in parallel. The upper half of the reverse drum controls motor No. *1*, and the lower half controls motor No. *2*.



Type 224 Controller
1 2 3 4 5
Forward
Reverse
Reverse Drum
Canopy Switch
Fuse
Main Drum
#1 Fuse
#2 Fuse
To Cut Out Motor #1 Remove Fuse #1
" " " " #2 " " #2
6600 V.
6300 V
6000 V
Lights
550 V
Neutralizing Winding
Ground Neutralizing Winding to Motor Frame
Preventive


ring A.C.
Controller
Type 224 Controller
1 2 3 4 5
Forward
Reverse
Reverse Drum
Canopy Switch
Main Drum
Fuses
250 V.
220 V.
190 V.
160 V.
Autotransformer
Ground to Frame
of Both Motors
R2
C2
e Coil

Resistances R_1 to R_5 and the upper portion of the direct-current drum are used in connection with motors Nos. *1* and *2*. Resistances R_6 to R_{10} and the lower portion of the direct-current drum are used in connection with motors Nos. *3* and *4*. The two alternating-current drums are geared together, so that while one is turning in one direction the other is moving in the opposite direction. The left-hand drum controls motors Nos. *1* and *2*, and the right-hand drum controls motors Nos. *3* and *4*. The car wires are marked by letters and subscripts. When direct current is to be used, one of the direct-current trolleys is placed on the wire and the emergency switch is thrown to its direct-current position. When alternating current is to be used, the alternating-current pantagraph trolley is placed on the wire, and the direct-current trolley is hauled down.

DIRECT-CURRENT CONTROL

39. The emergency switch, Fig. 29, is thrown to its direct-current position, and the left-hand segments of the No. *1* reverse switch are assumed to be in connection with the reverse-switch fingers.

On the **first point** of the direct-current drum, current takes the following path: *D.-C.* trolley–emergency switch –fuse–T–T–T finger of the *D.-C.* drum–*B.-O.* coil–D finger–drum segment–R_1–R_1–R_1–resistances between R_1 and R_5 –R_5–M_1 cut-out switch–M_1 reverse switch–F_2- –F_2+ –$F+$ –through field of No. *2* motor–$F-$ –$F-$ –through field of No. *1* motor–$F+$ –F_1–canopy switch–F_1+ –F_1+ –F_1+ –A_1+ –A_1+ –$A+$ –through armature of No. *1* motor–$A-$ –$A+$ –through armature of No. *2* motor–$A-$ –A_2- –A_2- –A_2- –finger A_2- –*D.-C.* drum segment–R_6–R_6–resistances–R_{10} –R_{10}–R_{10}–R_{10}–M_2–M_2–F_4- –F_4+ –F_4+ –$F+$ –through field of No. *4* motor–$F-$ –$F-$ –through field of No. *3* motor–$F+$ –F_3+ –F_3–canopy switch–F_3+ –F_3+ –F_3+ –A_3+ –A_3+ –A_3+ –$A+$ –through armature of No. *3* motor–$A-$ –$A+$ –through armature of No. *4* motor–$A-$ –G on motor frame. The four motors and all of the resistance sections are in series.

When the reverse drum is thrown from one position to the other, the field terminals are interchanged, while the armature terminals remain unchanged; this reverses the direction of rotation of the motors. The armatures and the neutralizing windings in series with them are grounded on the frames of the motors.

If four motors are to be used, motors Nos. *1* and *2* are connected permanently in series, as indicated by the small sketch on the left in Fig. 28, and are considered as one unit, so far as the controller connections are concerned. Motors Nos. *3* and *4* are also connected in series, as shown by the sketch on the right in Fig. 28, and considered as one unit. The two pair of motors thus formed are connected in multiple.

TYPE 455 CONTROLLER CAR-WIRING DIAGRAM

38. In Fig. 29 is shown a car-wiring diagram for two Westinghouse type 455 hand controllers that are designed for controlling a four-motor equipment of four 50-horse-power motors on either an alternating- or a direct-current system. When operating on alternating current, the *pantagraph trolley* is ordinarily used. This is controlled by means of an air valve in the motorman's compartment. When operating on direct current, either one of the wheel trolleys is used, according to the direction in which the car is running. The wheel trolleys are mounted on insulated bases, and an oil-insulated emergency switch is connected so that, in case of accident to the pantagraph trolley, throwing this emergency switch to the alternating-current position will permit either wheel trolley to be used on alternating current, and will thus enable the car to be brought back to the barn.

A canopy switch is used on each end of the car to enable power to be cut off in case the controller, for any reason, should stick on the on-position. Under such circumstances, opening the canopy switch will cut off power from the car and thus enable it to be stopped.

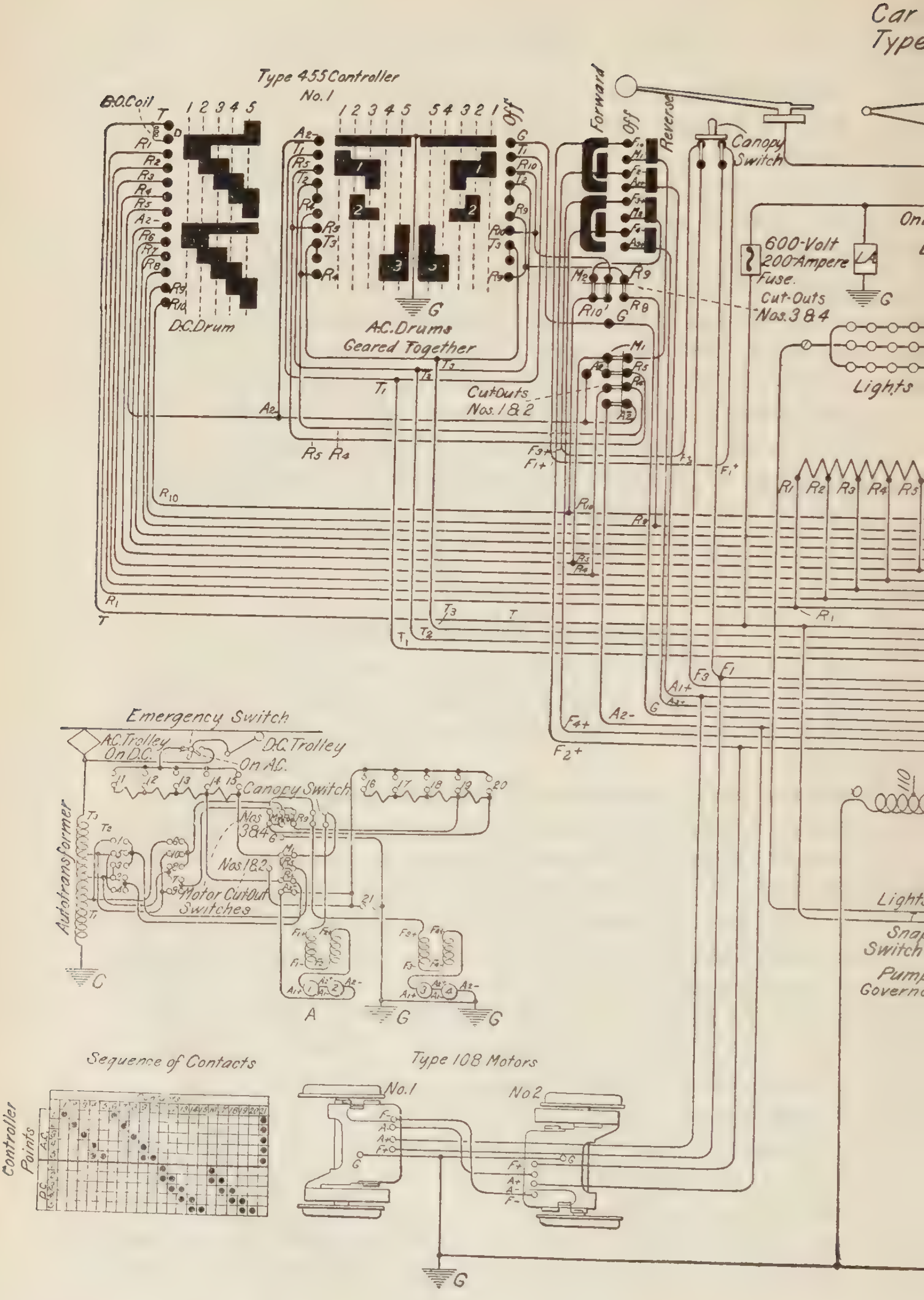
Each controller contains a direct-current drum, two alternating-current drums, a reverse switch, and cut-out switches.

Resistances R_1 to R_5 and the upper portion of the direct-current drum are used in connection with motors Nos. *1* and *2*. Resistances R_6 to R_{10} and the lower portion of the direct-current drum are used in connection with motors Nos. *3* and *4*. The two alternating-current drums are geared together, so that while one is turning in one direction the other is moving in the opposite direction. The left-hand drum controls motors Nos. *1* and *2*, and the right-hand drum controls motors Nos. *3* and *4*. The car wires are marked by letters and subscripts. When direct current is to be used, one of the direct-current trolleys is placed on the wire and the emergency switch is thrown to its direct-current position. When alternating current is to be used, the alternating-current pantagraph trolley is placed on the wire, and the direct-current trolley is hauled down.

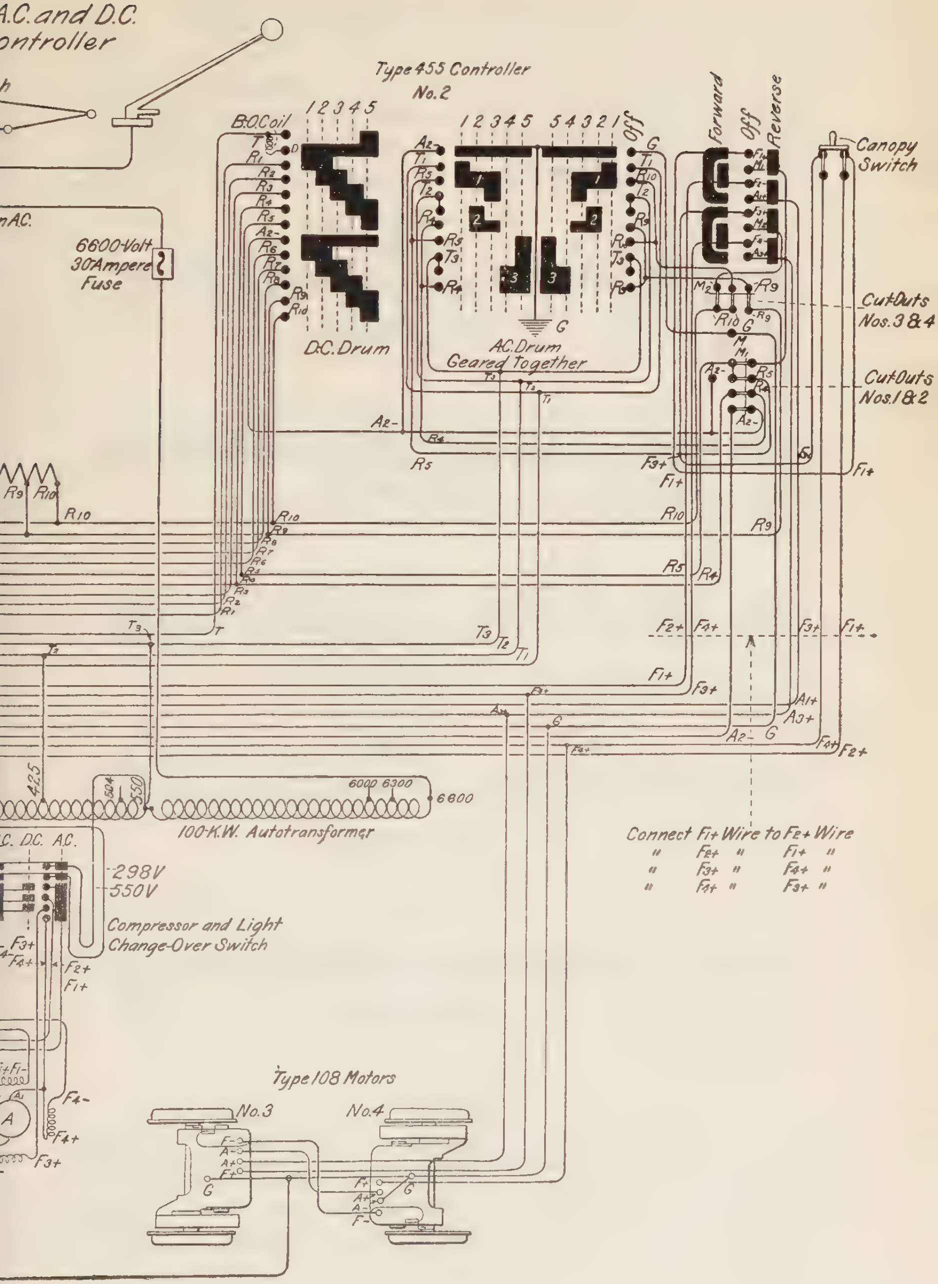
DIRECT-CURRENT CONTROL

39. The emergency switch, Fig. 29, is thrown to its direct-current position, and the left-hand segments of the No. *1* reverse switch are assumed to be in connection with the reverse-switch fingers.

On the **first point** of the direct-current drum, current takes the following path: *D.-C.* trolley–emergency switch –fuse–T–T–T finger of the *D.-C.* drum–*B.-O.* coil–D finger–drum segment–R_1–R_1–R_1–resistances between R_1 and R_5 –R_5–M_1 cut-out switch–M_1 reverse switch–F_2- –F_2+ –$F+$ –through field of No. *2* motor–$F-$ –$F-$ –through field of No. *1* motor–$F+$ –F_1–canopy switch–F_1+ –F_1+ –F_1+ –A_1+ –A_1+ –$A+$ –through armature of No. *1* motor–$A-$ –$A+$ –through armature of No. *2* motor–$A-$ –A_2- –A_2- –A_2- –finger A_2- –*D.-C.* drum segment–R_6–R_6–resistances–R_{10} –R_{10}–R_{10}–R_{10}–M_2–M_2–F_4- –F_4+ –F_4+ –$F+$ –through field of No. *4* motor–$F-$ –$F-$ –through field of No. *3* motor–$F+$ –F_3+ –F_3–canopy switch–F_3+ –F_3+ –F_3+ –A_3+ –A_3+ –A_3+ –$A+$ –through armature of No. *3* motor–$A-$ –$A+$ –through armature of No. *4* motor–$A-$ –G on motor frame. The four motors and all of the resistance sections are in series.



Car
Type
Type 455 Controller
No. 1
B.O. Coil
D.C. Drum
A.C. Drums
Geared Together
Forward
Off
Reverse
Canopy Switch
600-Volt
200-Ampere
Fuse.
Cut-Outs
Nos. 3 & 4
Cut Outs
Nos. 1 & 2
Lights
Emergency Switch
A.C. Trolley
On D.C.
D.C. Trolley
On A.C.
Canopy Switch
Nos. 3 & 4
Nos. 1 & 2
Motor Cut Out
Switches
Autotransformer
Sequence of Contacts
Controller
Points
A.C.
D.C.
Type 108 Motors
No. 1
No 2
Lights
Snap
Switch


A.C. and D.C.
Controller
Type 455 Controller
No. 2
B.O. Coil
D.C. Drum
A.C. Drum
Geared Together
Off
Forward
Off
Reverse
Canopy
Switch
Cut Outs
Nos. 3 & 4
Cut Outs
Nos. 1 & 2
6600-Volt
30 Ampere
Fuse
100-K.W. Autotransformer
298V
550V
Compressor and Light
Change-Over Switch
Type 108 Motors
No. 3
No. 4
Connect F1+ Wire to F2+ Wire
" F2+ " F1+ "
" F3+ " F4+ "
" F4+ " F3+ "

40. The connections of the motors on the first point, as well as on the four following points, are shown diagrammatically in Fig. 30. On the second point, Fig. 29, the sections of resistance between R_1 and R_2 and R_6 and R_7 are

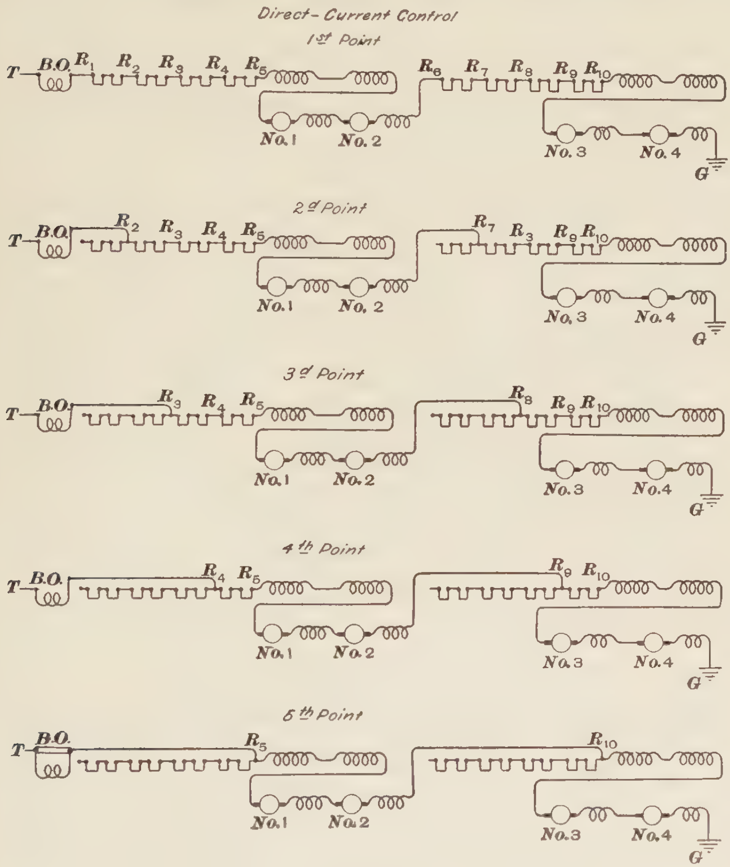


FIG. 30

cut out. On the third point, two more sections are cut out. On the fourth point, two sections are cut out. On the fifth point, the last two sections are cut out and the blow-out coil is short-circuited, thus leaving the four motors in series across the line.

ALTERNATING-CURRENT CONTROL

41. The pantagraph trolley, Fig. 29, is placed in operation, and the direct-current trolley is hauled down. The reverse switch is assumed to be in the same position as before, and the two alternating-current drums on controller No. *1* are operated. Current flows from the trolley wire through the alternating-current fuse and autotransformer to the ground. The lowest voltage tap is T_1, the next higher T_2, and the highest T_3.

42. On the **first point**, the current flows from tap T_1 to T_1, and to junction T_1 under the alternating-current drums. Part of the current flows to finger T_1 of the right-hand drum, and part to finger T_1 of the left-hand drum. Considering the left-hand drum, the path of the current is as follows: Finger T_1–R_5–R_5–R_5–M_1–M_1–F_2- –F_2+ –$F+$ –$F-$ –$F-$ –$F+$ –F_1–canopy switch–F_1+ –F_1+ –F_1+ –A_1+ –A_1+ –$A+$ –$A-$ –$A+$ –$A-$ –A_2- –A_2- –A_2- –A_2- finger on *A.-C.* drum–top drum segment to ground. Motors Nos. *1* and *2* are in series between tap T_1 and the ground.

By the action of the right-hand drum, motors Nos. *3* and *4*, which are permanently in series, are connected between tap T_1 and the ground. The two sets of motors are in parallel. This is shown diagrammatically in Fig. 31 at the first alternating-current point.

When moving to the **first intermediate position,** finger T_1, Fig. 29, does not leave contact with its drum segment until the lower finger T_2, which is connected to tap T_2, makes contact with its drum segment. At this intermediate position, on either of the two drums, a section of resistance is shunted between fingers T_1 and T_2, and immediately afterwards finger T_1 loses its contact and the resistance is left in series with tap T_2. Suppose that finger T_1 on the left-hand drum is touching the top of segment *1*, and that the lower finger T_2 is touching the top of segment *2*; there is then a path from the higher voltage finger T_2 to finger T_1 as follows: Lower finger T_2–

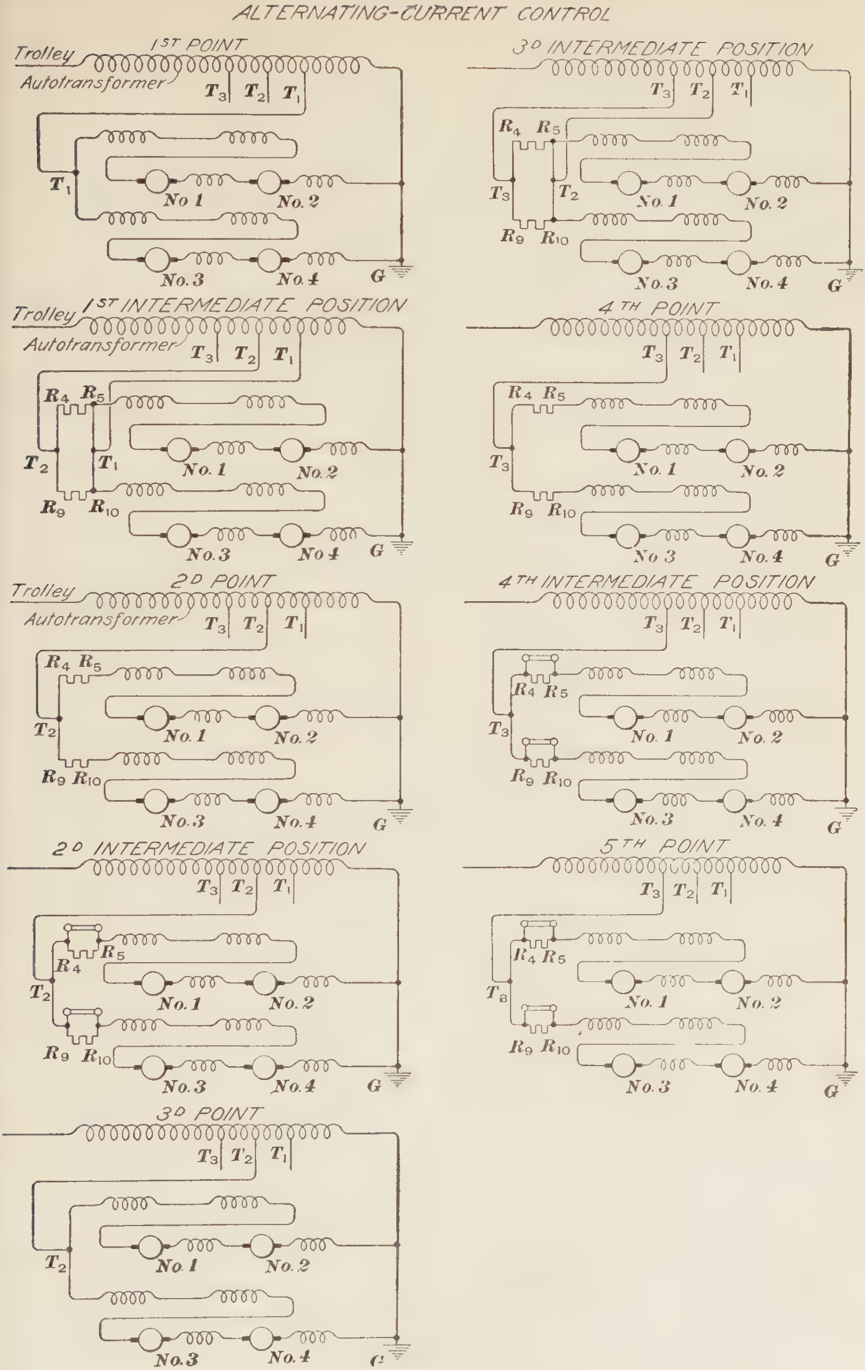

ALTERNATING-CURRENT CONTROL
1ST POINT
Trolley
Autotransformer
T3 T2 T1
T1
No. 1 No. 2
No. 3 No. 4
G
1ST INTERMEDIATE POSITION
R4 R5
T2 T1
R9 R10
2D POINT
2D INTERMEDIATE POSITION
3D POINT
3D INTERMEDIATE POSITION
4TH POINT
4TH INTERMEDIATE POSITION
5TH POINT
T3

Fig. 31

drum segment *2*–R_4–R_4–R_4–R_4–R_4–one resistance section –R_5–R_5–R_5–R_5–finger R_5–drum segment *1*–finger T_1. The section of resistance between R_4 and R_5 acts as a shunt on one drum, and the section of resistance between R_9 and R_{10} serves the same purpose on the other drum. The two sections of resistances are thus in parallel between taps T_1 and T_2, as indicated at the first intermediate position, Fig. 31.

43. When the drums, Fig. 29, are turned to the **second point**, fingers T_1 lose contact with segments *1*, and a resistance section is left in series with each set of motors, as shown in Fig. 31 at the second point.

On the **second intermediate position**, finger T_2, Fig. 29, makes contact with segment *1*. Current can now flow from T_2–segment *1*–R_5–R_5–R_5–M_1–M_1–F_2–F_2+ and through motors Nos. *1* and *2*. Upper finger T_2 touches segment *1*, and lower finger T_2 touches segment *2*, thus short-circuiting the resistance section between R_4 and R_5, as shown at the second intermediate position, Fig. 31. Similar action takes place on the other alternating-current drum.

44. On the **third point**, lower finger T_2, Fig. 29, drops contact with segment *2*, and upper finger T_2 remains in contact with segment *1*. The two sets of motors are connected between tap T_2 and the ground, as shown in Fig. 31, third point.

When the **third intermediate position** is reached, lower finger T_3, Fig. 29, touches segment *3*, and upper finger T_2 touches segment *1*. Taps T_3 and T_2 are shunted by one resistance section on each drum. The resistance section between R_4 and R_5 is connected between lower finger T_3 and upper finger T_2, on the left-hand drum, and the resistance section between R_9 and R_{10} is connected between the corresponding fingers on the right-hand drum. On this position, finger T_3 is in contact through segment *3* with R_4, and finger T_2 is in contact through segment *1* with R_5. The motor connections are shown at the third intermediate position, Fig. 31.

45. On the **fourth point,** fingers T_2 and R_8, Fig. 29, drop contact with segment *1*. A resistance section is left in series with each set of motors, as shown in Fig. 31, fourth point.

When the **fourth intermediate position** is reached, finger R_5, Fig. 29, makes contact with segment *3*, and as fingers R_5 and R_4 are now in contact with the same segment, the resistance section connected to each drum is short-circuited. The motor connections are shown at the fourth intermediate position, Fig. 31.

46. On the **fifth point,** Fig. 29, the conditions are the same as on the fourth intermediate position. The resistances are short-circuited, and the sets of motors are connected in parallel between the high-voltage tap T_3 and the ground.

47. The pump motor for operating on either alternating current or direct current is arranged so that it operates with all the field coils in series on direct current, and all in parallel on alternating current. A change-over switch is used for varying these connections. The same switch also connects the lighting circuit to the transformer when the car is on alternating current; or, to the wheel trolley when it is on direct current. When the car is on direct current, the change-over switch is thrown so that the direct-current segments are in contact with the fingers. On alternating-current operation, the alternating-current segments are in contact with the fingers.

48. The small sketch at the left in Fig. 29, shows diagrammatically the contacts that are necessary for the operation of the controller. The order in which the contacts are opened and closed on the different controller points is indicated by the tabular arrangement of sequence of contacts.

WESTINGHOUSE UNIT-SWITCH, ALTERNATING-CURRENT CONTROL

TYPE 334-A CONTROLLER

49. The controlling apparatus used with the Westinghouse unit-switch, alternating-current control system is, in general, similar to that employed in the Westinghouse unit-switch control systems arranged for direct-current motors. A small storage battery furnishes the direct current for the control circuits in both systems.

In Fig. 32 is shown a type 334-A master controller, and

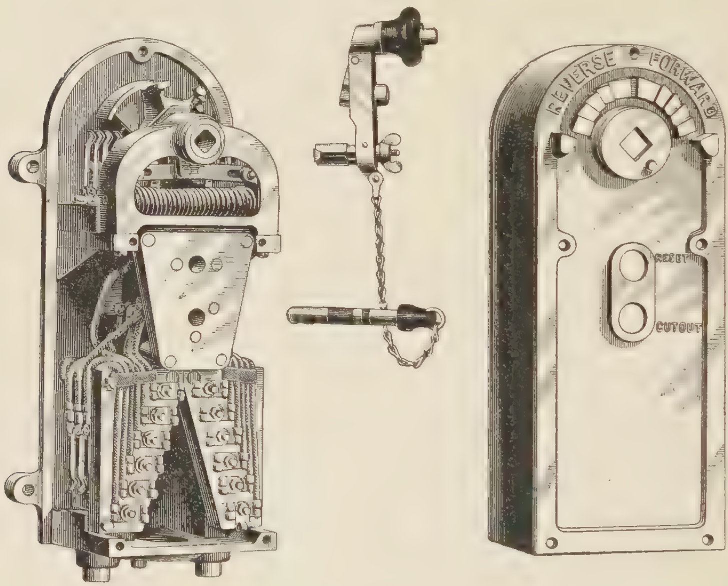
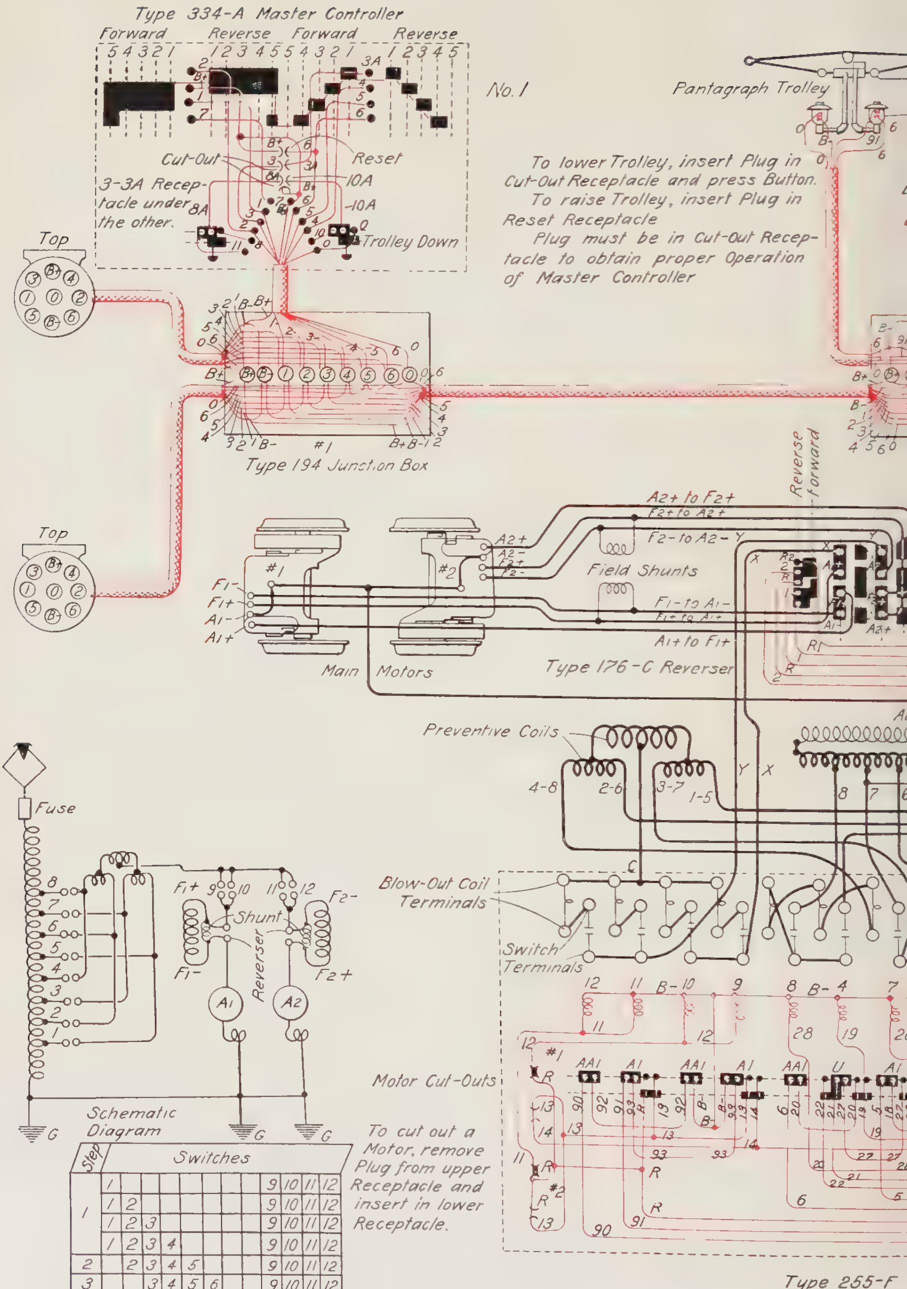


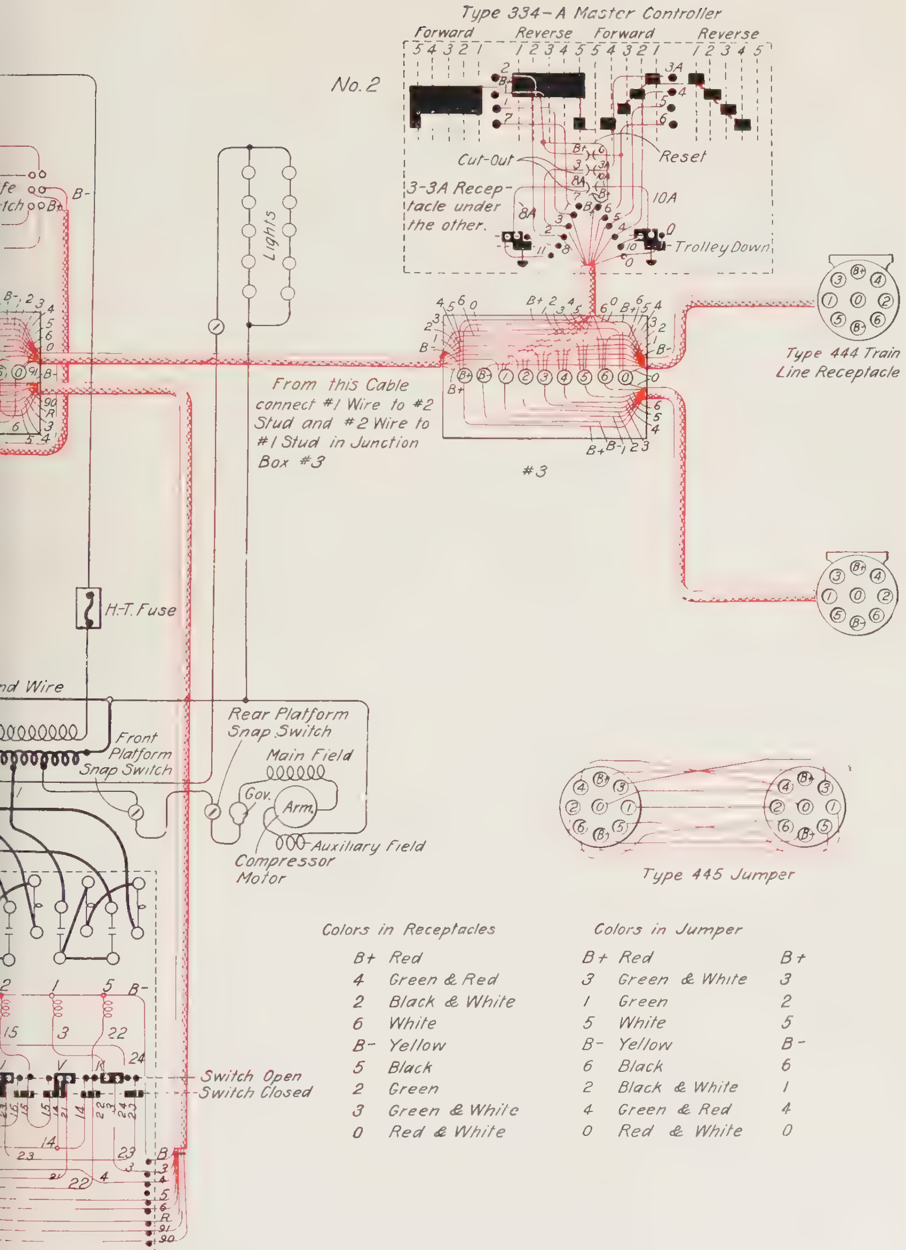
Fig. 32

in Fig. 33, a car-wiring diagram for a type 255-F switch group and two 100-horsepower motors. For a four-motor equipment of the same size of motors, operating on a 3,300-volt circuit, the connections would be essentially the same. In the latter case, however, the motors would



Step	Switches											
1	1								9	10	11	12
	1	2							9	10	11	12
	1	2	3						9	10	11	12
	1	2	3	4					9	10	11	12
2		2	3	4	5				9	10	11	12
3			3	4	5	6			9	10	11	12
4				4	5	6	7		9	10	11	12
5					5	6	7	8	9	10	11	12

Sequence of Switches



Colors in Receptacles

B+	Red
4	Green & Red
2	Black & White
6	White
B-	Yellow
5	Black
2	Green
3	Green & White
0	Red & White

Colors in Jumper

B+	Red	B+
3	Green & White	3
1	Green	2
5	White	5
B-	Yellow	B-
6	Black	6
2	Black & White	1
4	Green & Red	4
0	Red & White	0

CAR-WIRING DIAGRAM A.C. FOR TYPE 255-F SWITCH GROUP FOR TWO MOTORS

§51 26874

be connected two in series. With a four-motor equipment of such motors, on a 6,600-volt circuit, a circuit-breaker would be used in the high-tension circuit instead of a fuse.

TYPE A.-C. UNIT-SWITCH CONTROL, CAR-WIRING DIAGRAM

50. Operation of the Trolley.—The pantagraph type of trolley is indicated in Fig. 33. This device will be described in more detail later. The trolley is raised into contact with the trolley wire by springs and is lowered by air pressure, both movements being controlled by magnets and air valves. The storage-battery switch is closed, so that either one battery or the other is connected to the control circuit. To raise the trolley, insert the plug shown in Fig. 32 into the reset receptacle on controller No. *1*, Fig. 33, thus joining contacts $B+$ and *6*. Starting from the positive battery terminal $B+$, the current path is as follows: $B+$–knife switch–$B+$–$B+$–$B+$–$B+$–$B+$–$B+$–$B+$–$B+$–$B+$–$B+$–plug in reset receptacle–*6–6–6–6–6–6–6–6–6–6*–right-hand control magnet under the pantagraph trolley–*91–91–91–91–91–91*–interlock A_1 of switch *11* on switch group–*93–93–93–93*–interlock A_1 of switch *9*–$B-$–$B-$–negative battery wire, back to the negative terminal of the battery. The right-hand trolley control magnet is energized, admitting air to the trolley unlock cylinder; this releases the latch that holds the trolley in its lower position and allows powerful springs to raise the trolley into its active position.

To lower the trolley, the controller plug, which has two metal portions insulated from each other, is inserted into the cut-out receptacle, thus connecting together the upper cut-out receptacle contacts $B+$, *8 A*, and *10 A*, and also the lower cut-out receptacle contacts *3* and *3 A*. The right-hand button, shown near the base of the controller in Fig. 32 and indicated in Fig. 33, is then pressed. The button temporarily raises the trolley segments so that fingers *10 A* and *0* are connected. Starting from the upper cut-out receptacle contact $B+$ on the controller, the path is: $B+$–plug–contact *10 A*–finger *10 A*–trolley segment–finger *0*–wire *0*, through

junction boxes to the left-hand control, or valve, magnet under the pantagraph trolley-wire $B-$, to negative terminal of the battery. The control magnet admits air to the trolley and forces it to its lower position, where it is locked.

All of the trolleys on the train may be operated from any one of the master controllers through the interconnecting control wires on the cars.

51. First Notch.—When the No. *1* controller, Fig. 33, is to be operated, the controller plug is inserted into the cut-out receptacle. Since the button on the controller base is not pressed, the trolley control circuit is inactive. One of the metal portions of the plug connects receptacle contacts *3* and *3 A*. In order to obtain forward movement of the car, the controller handle is moved toward the right. On the first forward notch, drum finger $B+$ is connected through one of the drum segments, all of which are electrically connected, to finger *1*. The path is: finger $B+$–finger *1*–junction boxes Nos. *1* and *2*–reverser $1–R_1–R_1–90–90–90–90–90–90–90–A\,A_1–92–92–A\,A_1–B-$. The reverser is thrown to forward position, and reverser fingers *1* and R are connected by the lower reverser segment. Current now flows through $1–R–R–R$–switch group $R–R–R–R$–magnet coils *9*, *10*, *11*, and *12* in parallel. This operates main switches *9*, *10*, *11*, and *12*, and opens their interlocks A_1, $A\,A_1$, A_1, and $A\,A_1$.

At the same time, drum finger $B+$ is connected to finger *3 A*. Current flows through finger *3 A*–contact *3 A*–plug–contact *3*–wire *3*, through junction boxes Nos. *1* and *2*–switch group *3–3–3*–interlock K–*3*–magnet coil *1*–common battery wire $B-$. Main switch *1* and its interlock V are closed. Autotransformer tap *1* is connected to end *1* of the right-hand preventive coil.

Since the interlocks under switches *11*, *9*, and *1* are closed, current can flow from wire R, under the interlock of switch *11*, to interlock A_1–*13–13–13–14–14–14–14–14–14*–interlock V–*15–15–15*–magnet coil $2–B-$. Main switch *2* is now closed, connecting autotransformer tap *2* to end *2* of the left-hand preventive coil.

Since the interlock under main switch *2* is now closed, current can flow from junction *14* under this interlock to interlock *U–17–17–17–17–17*–magnet coil *3–B–*. Main switch *3* is closed, connecting tap *3* to end *3* of the right-hand preventive coil.

Since interlock *U* under main switch *3* is now closed, current can flow from junction *14*, under this interlock, to *19–19–19–19–19*–magnet coil *4–B–*. Main switch *4* is closed, connecting tap *4* to end *4* of the left-hand preventive coil.

Main switches *1*, *2*, *3*, *4*, *9*, *10*, *11*, and *12* and their interlocks are closed on the first notch, as indicated in the table of sequence of switches.

52. Second Notch.—On the second notch, finger *3A*, Fig. 33, drops contact, and finger *4* makes contact with the drum. Opening the circuit of finger *3A* opens main switch *1*, its tap circuit, and its interlock *V*. From drum finger *4*, current flows through wire $4–A_1–16–16–16$–interlock *U–15*–magnet coil *2*. Switch *2* is held closed, although its control path through interlock *V* is broken. From junction *14*, under interlock *V*, current can now flow to interlock *V* (open)*–21–21–21–21*–interlock *U* (closed)*–22–22–22–22–22*–magnet coil *5–B–*. Main switch *5* and its interlock are closed, and tap *5* is connected to end *5* of the right-hand preventive coil. The manner of advancing the tap connections is similar to that indicated in Fig. 22. Switches *2*, *3*, *4*, *5*, *9*, *10*, *11*, and *12*, Fig. 33, are active on the second notch.

53. Third Notch.—Drum finger *4*, Fig. 33, drops contact, and finger *5* makes contact. Wire circuit *4* is broken; thus, magnet *2* opens main switch *2* and its interlock *U*. Current from drum finger *5* now flows through interlock A_1 of switch *7–18–18*–interlock *U* of switch *3* (closed)*–17–17*–magnet coil *3–B–*. Switch *3* is held closed, although its control path through interlock *U* of switch *2* is open. Current from junction *14*, under interlock *U* of switch *2* can flow to interlock *U–23–23–23–23*–interlock *K* (closed)*–24–24–24*–magnet coil *6–B–*. Main switch *6* and its interlock are closed. Tap *6* is connected to end *6* of the left-hand preventive coil.

Switches *3*, *4*, *5*, *6*, *9*, *10*, *11*, and *12* are active on the third notch.

54. Fourth Notch.—Drum finger *5*, Fig. 33, drops contact, and finger *6* makes contact. Wire circuit *5* is broken; thus, magnet *3* opens main switch *3* and its interlock *U*. From drum finger *6*, current now flows through interlock $A A_1$ of switch *8–20–20*–interlock *U* (closed)–*19–19* –magnet coil *4–B–*. Switch *4* is held closed, although its control path through interlock *U* of switch *3* is open. Current from junction *14* can now flow through interlock *U* of switch *3–25–25–25–25*–interlock A_1 of switch *6* (closed)–*26–26* magnet coil *7–B–*. Main switch *7* and its interlock are closed. Tap 7 is connected to end *7* of the right-hand preventive coil. Switches *4*, *5*, *6*, *7*, *9*, *10*, *11*, and *12* are active on the fourth notch.

55. Fifth Notch.—Drum finger *6*, Fig. 33, drops contact, and finger 7 makes contact. Wire circuit *6* is broken; thus, magnet *4* opens main switch *4* and its interlock. Current cannot flow from drum finger 7, since controller terminal 7 is not connected to any car wire. Interlock *U* of switch *4* is open, so that current can now flow from junction *14* under interlock *V* of switch *1–21–21–21–21*–interlock *U–27–27–27–27*–interlock A_1 of switch *7* (closed)–*28–28–28–28*–magnet coil *8–B–*. Main switch *8* and its interlock are closed. Tap *8* is connected to end *8* of the left-end preventive coil. Switches *5*, *6*, *7*, *8*, *9*, *10*, *11*, and *12* are active on the fifth notch.

56. Five distinct voltages are impressed on the motor circuit by the action of the controller, and thus five efficient running notches are provided. From point *C*, Fig. 33, on the wire leading from the center of the upper preventive coil, current flows through the windings of the two motors, which are connected in parallel. With some motors, shunts across the field coils are used, but with other motors, they are omitted.

57. Fifth Reverse Notch.—To reverse the direction of movement of the car, the controller handle is thrown to

the left. On the first reverse notch, Fig. 33, drum fingers $B+$ and *2* are active. Current flows from drum finger *2* through junction boxes Nos. *1* and *2*–reverser *2–2–2–*R_2, now connected to *2*, as the reverser control segments are now assumed to be at forward position–R_2 operating coil–*90–90*–switch group *90–90–90*–interlock AA_1 of switch *12–92–92*–interlock AA_1 of switch *10–B– –B–*. The reverser operating coil R_2 forces the reverser contact segments to reverse position. Reverser finger R_2 drops contact with its segment, thus breaking connection between it and finger *2*. At the same time finger R makes contact with the same segment. Current flows from reverser finger *2* to finger *R–R*–wire *R*–switch group *R–R–R–R– –*magnet coils *9*, *10*, *11*, and *12*, in parallel, thus operating the main switches *9*, *10*, *11*, and *12*.

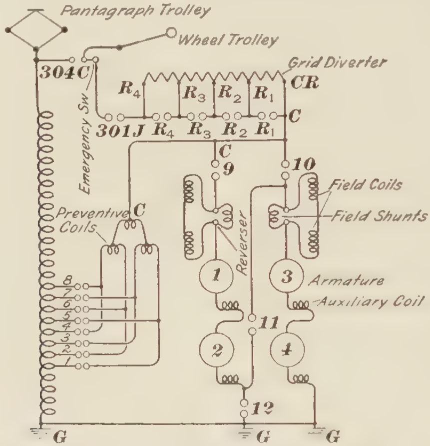
The action of the other control magnets and main switches is the same on the reverse notches as on the forward notches. The main field-coil connections of the motor are reversed; therefore, the rotation of the motors is reversed.

Assuming the reverser to be in its reverse position, as indicated by the position of the reverser control segments in Fig. 33, and the controller to be on the first forward notch, current from drum finger *1* flows to reverser finger *1*–finger R_1–operating coil R_1–*90*–through interlocks of open switches *12* and *10–B–*. The operating coil R_1 forces the reverser segments into their forward position, and the motors are then connected for forward rotation.

WESTINGHOUSE UNIT-SWITCH, ALTERNATING-CURRENT AND DIRECT-CURRENT CONTROL, SCHEDULE T

58. The connections of the motors and main switches for the unit-switch, alternating- and direct-current control system, schedule T, for four motors of a capacity above 75 horsepower and including 100 horsepower, each, are shown in Fig. 34. When alternating-current control is used, switches Nos. *9*, *10*, and *12* are closed, thus connecting the pairs of motors in parallel. The action of the

other alternating-current switches is similar to that described in connection with Fig. 33. On the first direct-current step, Fig. 34, switches Nos. *9*, *11*, and *301 J* are closed. The four motors are then connected in series, with all the resistance in circuit. A resistance section is cut out on each of the

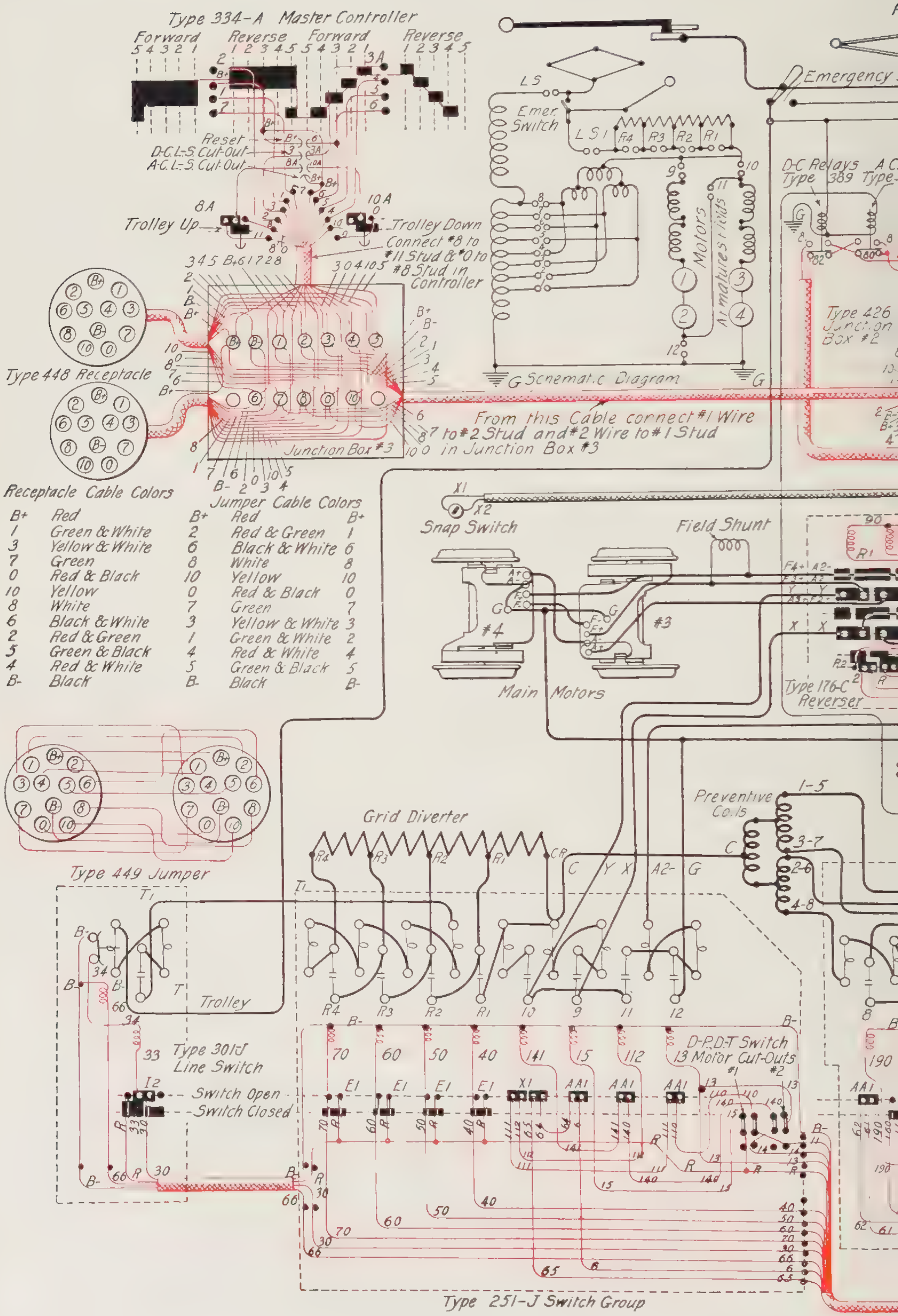


	Step	Switches																
A.C.		1								9	10		12					
		1	2							9	10		12					
		1	2	3						9	10		12					
	1	1	2	3	4					9	10		12					
	2		2	3	4	5				9	10		12					
	3			3	4	5	6			9	10		12					
	4				4	5	6	7		9	10		12					
	5					5	6	7	8	9	10		12					
DC	1									9		11		301J				
	2									9		11		301J	R1			
	3									9		11		301J	R1	R2		
	4									9		11		301J	R1	R2	R3	
	5									9		11		301J	R1	R2	R3	R4

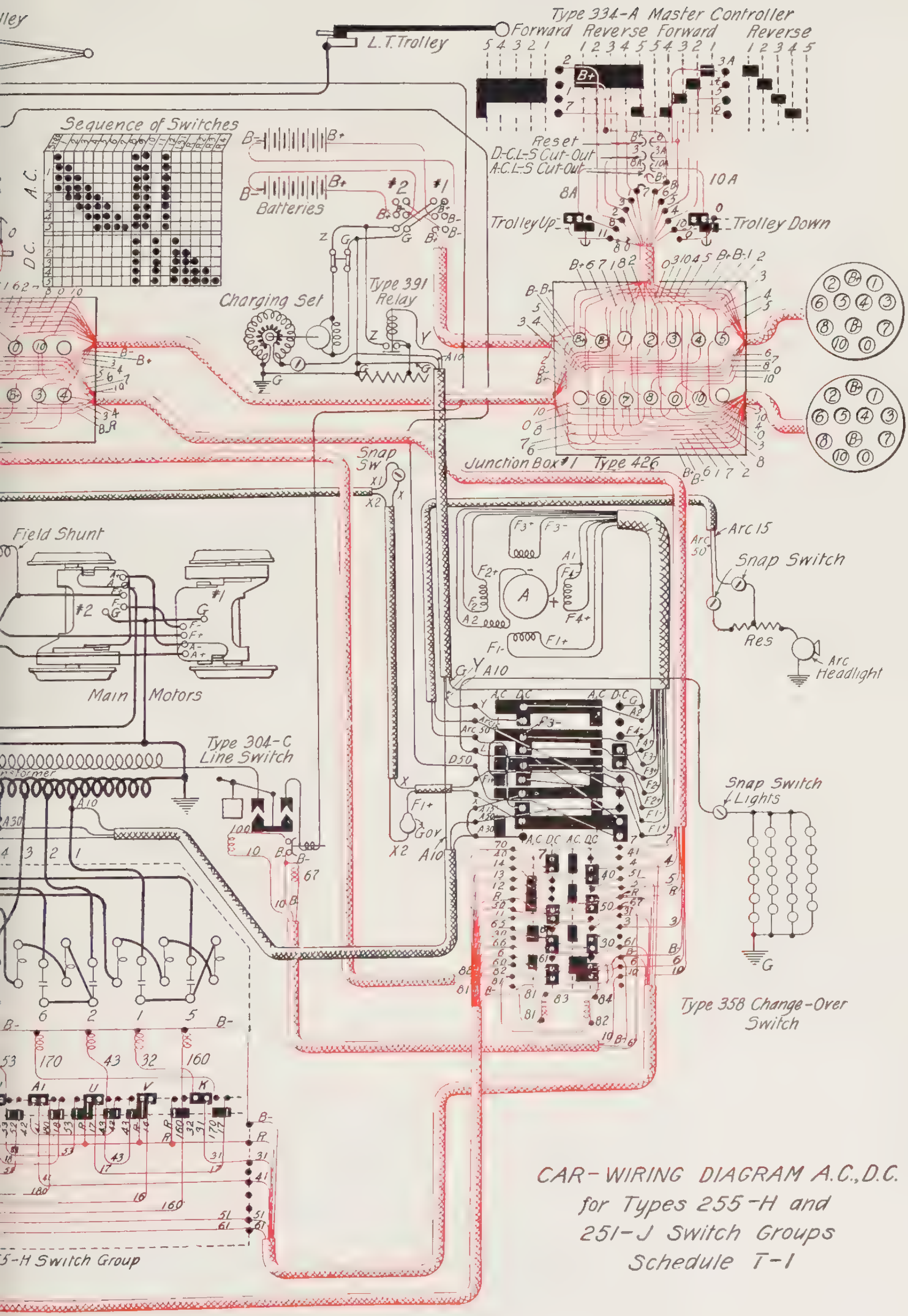
FIG. 34

succeeding steps, so that on the fifth step, only the four motors are in series across the line.

A change-over switch is provided. This switch is operated by two relays, so that when alternating current is used, the alternating-current relay operates to move the switch into its alternating-current position. When direct current is used, the direct-current relay operates to move the switch into its direct-current position. All of the circuits from the master controllers to the various switches pass through the change-



Type 334-A Master Controller
Forward 5 4 3 2 1
Reverse 1 2 3 4 5
Forward 5 4 3 2 1
Reverse 1 2 3 4 5
Reset
D-C L-S Cut-Out
A-C L-S Cut-Out
Trolley Up
Trolley Down
Connect #8 to #11 Stud & #0 to #8 Stud in Controller
Type 448 Receptacle
Junction Box #3
From this Cable connect #1 Wire to #2 Stud and #2 Wire to #1 Stud in Junction Box #3
Emer. Switch
Motors
Armatures Fields
Schematic Diagram
Emergency
D-C Relays Type 389
Type 426 Junction Box #2
Snap Switch
Field Shunt
Main Motors
Type 176-C Reverser
Receptacle Cable Colors
B+ Red
1 Green & White
3 Yellow & White
7 Green
0 Red & Black
10 Yellow
8 White
6 Black & White
2 Red & Green
5 Green & Black
4 Red & White
B- Black
Jumper Cable Colors
B+ Red B+
2 Red & Green 1
6 Black & White 6
8 White 8
10 Yellow 10
0 Red & Black 0
7 Green 7
3 Yellow & White 3
1 Green & White 2
4 Red & White 4
5 Green & Black 5
B- Black B-
Type 449 Jumper
Grid Diverter
Preventive Coils
Trolley
Type 301-J Line Switch
Switch Open
Switch Closed
D-P.D-T Switch
13 Motor Cut-Outs
Type 251-J Switch Group



CAR-WIRING DIAGRAM A.C., D.C.
for Types 255-H and
251-J Switch Groups
Schedule T-1

5 51 26874

over switch. In exactly the same way, the movement of the master controller operates the proper switches for direct- or alternating-current operation, according to which current is in use, and the position of the change-over switch.

WESTINGHOUSE UNIT-SWITCH, ALTERNATING-CURRENT AND DIRECT-CURRENT CONTROL, SCHEDULE T-1

59. Fig. 35 shows an alternating- and direct-current car-wiring diagram for types 255-H and 251-J switch groups, schedule T-1, with four motors. The change-over switch is operated for direct current as follows: Insert the plug into the controller cut-out of the left-hand controller. Contact *B*+ is connected to contact *8 A*, and current flows to *8 A*–stud *11*–wire *8*–contact point *8* on *A.-C.* relay (lower position)–*81* on *D.-C.* relay (upper position, as relay is now active)–*81*–*D.-C.* operating coil of change-over switch–*83*–change-over switch segment, if switch has been left at *A.-C.* position–*B*—. The switch is pulled to the direct-current position. If alternating current is to be used, wire *8* connects to upper point *8* on the alternating-current relay (now active) and current flows across the disk contact to *82* (lower position of *D.-C.* relay)–*82*–*A.-C.* operating coil of change-over switch–*84*–*B*—. If the switch is in direct-current position, it is pulled into alternating-current position.

60. Direct-Current Operation.—When the controller is thrown to the **first notch**, finger *3 A* is active, and current flows through the plug to contact *3* of the *D.-C.* line-switch cut-out–wire *3*–finger *30* on the change-over switch–interlock of *D.-C.* line switch–*33*–line-switch operating coil–*34*–*B*—. The line switch is thus closed.

Finger *1* is the forward reverser finger. When this finger is active, the reverser is thrown to forward position. Wire *R* at the reverse is now active, and the operating coil of switch *9* takes current from this wire. Switch *9* closes. Finger *11* on the change-over switch is energized from finger *R*, and current flows through *11*–*110*–*111*–*112*–operating coil of

switch *11*. Switch *11* closes. The four motors are in series, with all the resistance sections in circuit.

Further movement of the controller energizes fingers *4*, *5*, *6*, and *7* and cuts out the four resistance sections. The four motors are now in series, with all the resistance sections cut out.

61. Alternating-Current Operation.—The alternating-current line switch is closed by current that flows from *B*+ through cut-out contact *10 A* (plug in *A.-C.* line-switch cut-out)–finger *10*–wire *10*–operating coil of the *A.-C.* line switch–*B*−. The pantagraph trolley is raised after the plug is inserted in the alternating-current, line-switch cut-out by pressing the left-hand button at the base of the controller. Stud *8* and wire *0* are now active, and current flows through the operating coil of the trolley lock. The latch on the trolley is released, and the trolley is forced upwards by its springs.

As soon as the trolley touches the trolley wire, current flows through the alternating-current relay from autotransformer tap *4*. Contact is broken between lower points *8* and *80*. Therefore, when the left-hand button on the base of the controller is released and finger *8 A* is connected to stud *11* and wire *8*, no current can flow between points *8* and *80* and through the trolley-down magnet because of the break in the circuit at the alternating-current relay. If the trolley is to be lowered, the right-hand button is pushed, thus breaking wire circuit *10* and opening the alternating-current, 304-C line switch. The alternating-current relay contact plate drops and completes wire circuit *8* through the trolley-down magnet. Air under pressure is forced into the main cylinder of the pantagraph, and the trolley is lowered and automatically latched. If the trolley is to remain down, the plug may be drawn out of the alternating-current, line-switch cut-out. For alternating-current control, the plug is inserted in the alternating-current, line-switch cut-out, and the change-over switch is then forced to its alternating-current position as previously explained.

62. On the **first notch**, either finger *1* or *2* is active, depending on whether the controller is thrown to forward or

to reverse position. Wire *R* is energized (which also energizes wires *14* and *15* at the alternating-current position of the change-over switch) and switches *9*, *10*, and *12* are closed. Switch *1* is closed by current through finger *B* + – finger *3 A* – wire *3–A.-C.* segment of change-over switch–wire *31–32*–operating coil of switch *1*. Switch *2* is closed by current from wire *R* through the closed interlock of switch *1* and wire *43*. Switch *3* is closed by the current passing through the closed interlock of switch *2* and wire *53*. Switch *4* is closed by the current passing through the closed interlock of switch *3* and wire *63*.

On the **second notch,** finger *3 A* drops contact, and switch *1* opens. When wire *4* becomes active, wire *41* is energized at the change-over switch and switch *2* is held closed. The current can now flow through the wire *R*–interlock of switch *1* (open)–*16*–interlock of switch *4* (closed)–*160*–operating coil of switch *5*. Switch *5* closes.

On the **third notch,** finger *4* drops contact, and finger *5* is energized. Switch *2* opens, since wire *41* is dead, and circuit *R*, through its operating coil, was broken when switch *1* opened. Current from wire *R* flows through the interlock of switch *2* (open)–*17–17*–interlock of switch *5* (closed)–operating coil of switch *6*. Switch *6* closes. Circuit *R*, through the operating coil of switch *3*, is broken by the interlock of switch *2* (now open), but current flows through operating coil *3* from wire *51*.

On the **fourth notch,** wires *5* and *51* are dead, and wire *61* is active. Switch *3* opens because wire *51* is dead. Current from the wire *R* flows through the interlock of switch *3* (open)–*18–180*–operating coil of switch *7*. Switch *7* closes. Circuit *R*, through the operating coil of switch *4*, is now broken, but the coil obtains current from wire *61*.

On the **fifth notch,** wires *6* and *61* are dead, and switch *4* opens. Wire *7* is dead when the change-over switch is at its alternating-current position. Current from circuit *R* can now flow through the interlock of switch *1–16–19–190*–operating coil of switch *8*. Switch *8* closes. The maximum electromotive force is now impressed on the motors.

GENERAL ELECTRIC T-33 CONTROLLER

63. In Fig. 36 is shown a T-33, hand-operated controller that is arranged for the control of motors on either alter-

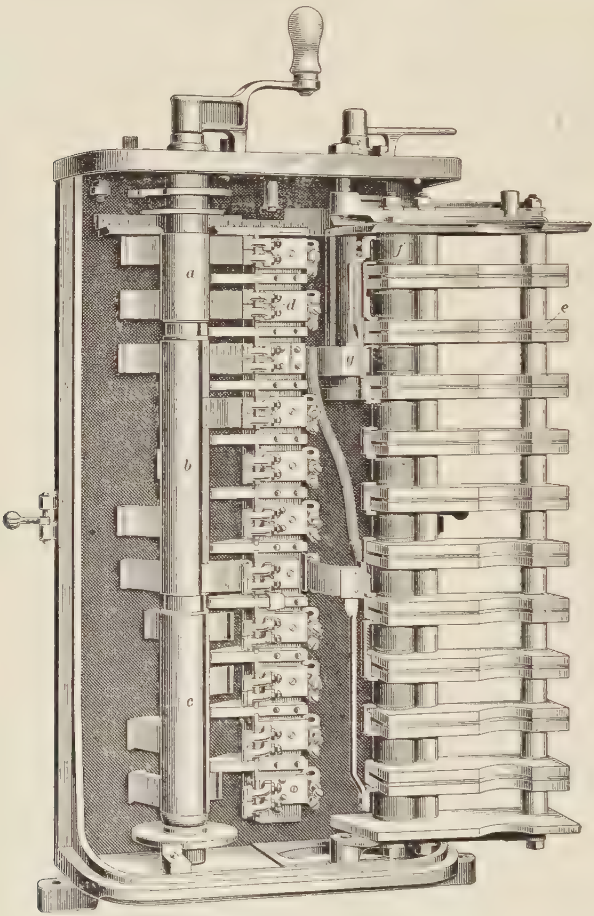
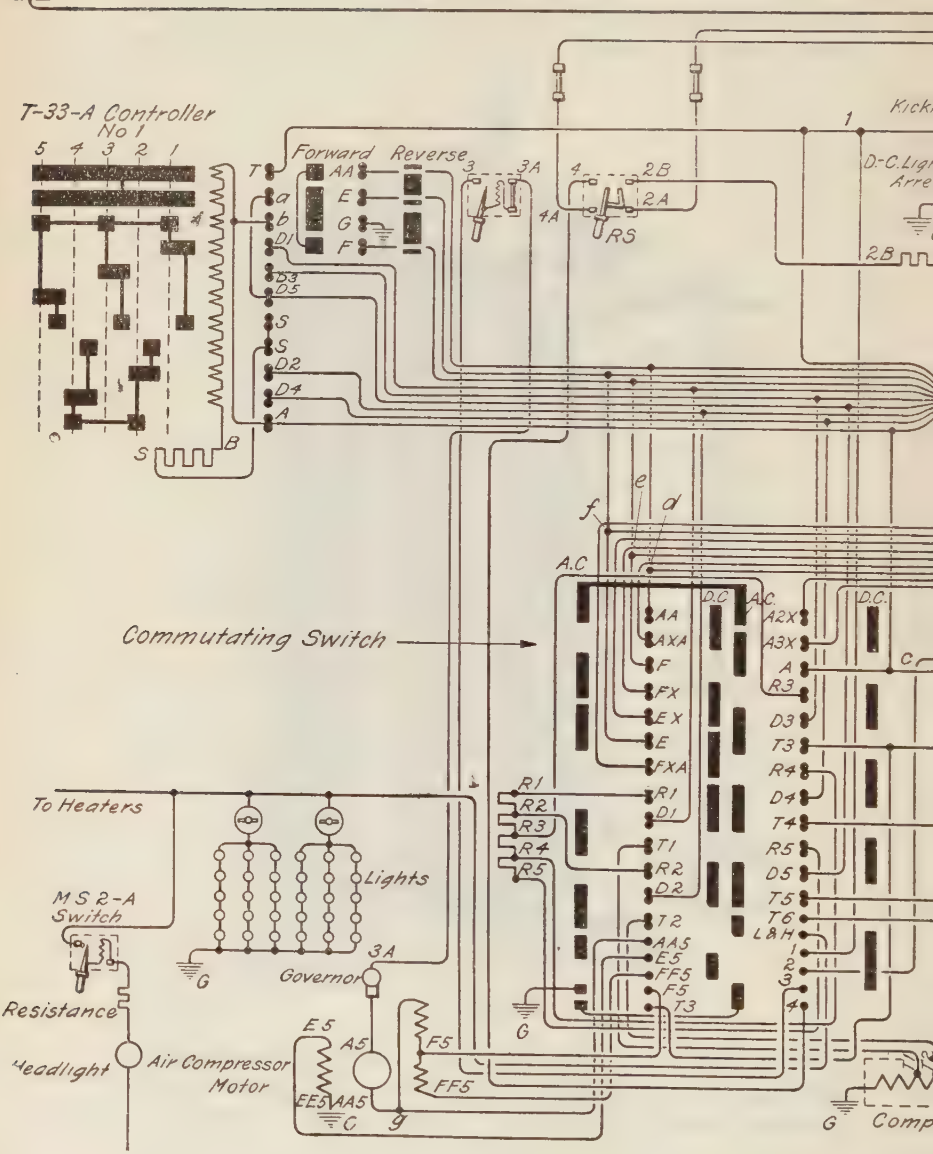


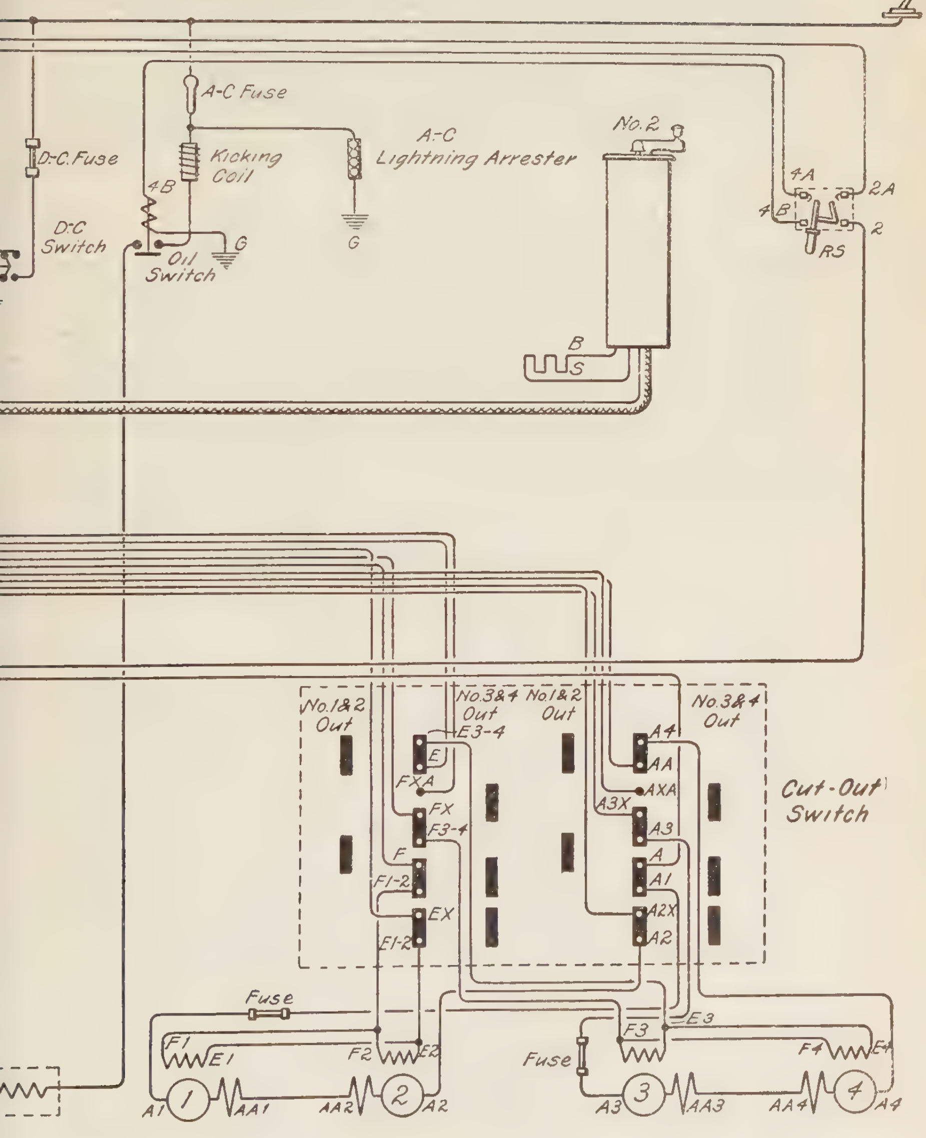
FIG. 36

nating- or direct-current circuits. The controller drum is divided into three sections *a*, *b*, and *c* that are insulated from one another. The fingers *d* bear on the drum segments

Car Wiring for Four G.E.-605 Com



ated Motors A.C.-D.C. Operation



when the controller is in operation. The arc guards *e*, when in their closed position, pass between the contact segments and thus prevent current from arcing across from segment to segment. Small blow-out magnets *f* that are provided with polar extensions embedded in the arc guards serve to disrupt any arc that may tend to hold between the segments and the fingers. The reverse switch is shown at *g*.

T-33-A CAR-WIRING DIAGRAM

64. In Fig. 37 is shown a car-wiring diagram arranged for T-33-A controllers and four motors, operating on either alternating- or direct-current circuits. The alternating- and the direct-current main switches are provided with retaining coils. After the switch has been closed, the retaining coil holds it in that position until the voltage drops to half of its normal value, when the coil automatically releases and opens the switch. A retaining-coil switch *RS* is placed in each cab, and the main switch may be thrown open by operating either retaining-coil switch.

DIRECT-CURRENT CONTROL

65. The action of controller No. *1* will be considered. The reverse-switch fingers are assumed to be in contact with the left-hand, or forward, segments, and the fingers on the commutating switch, to rest on the direct-current segments. The direct-current main switch is closed by hand, and both retaining switches are thrown over so that the right-hand blades connect *2 A* with *2 B*, and *2* with *2 A*. The current through the retaining coil takes the following path: Trolley–*D.-C.* fuse–*D.-C.* switch–kicking coil–*1*–finger *1* on commutating switch–*D.-C.* segment–*2*–*2*–*2 A*–*2 A*–*2 B*–*2 B*–resistance –retaining coil–ground at *G*.

66. When the controller, Fig. 37, is advanced to the **first point**, current flows through the kicking coil to finger *T* on the controller. From this point, the path is: *T*–drum segments–*a*–*D 5*–*D 5*–*R 5*–*R 5*–*R 4*–*R 3*–*R 2*–*R 1*–*R 1*–*D 1*–*D 1*–

b–A–A on cut-out switch–*A 1*–fuse–*A 1–1–A A 1–A A 2–2–A 2–A 2–A 2 X–A 2 X–A 3 X–A 3 X–A 3*–fuse–*A 3–3–A A 3–A A 4–4–A 4–A 4–A A–d–A A* reverse switch–forward segments–*F–e–F* on the cut-out switch–*F 1-2*–Nos. *1* and *2* fields in parallel–*E 1-2–E X–E X–F X–F X–F 3-4*–fields Nos. *3* and *4* in parallel–*E 3-4–E–f–E* reverse switch–*G*. The four motors and all the resistance sections are in series. The four armatures and their compensating coils are in series. The four fields are divided into two sets, which are in series, each set consisting of two fields in parallel.

67. On the **second point**, finger *D 2*, Fig. 37, is connected to finger *A*. Drum finger *D 2* is also connected to commutating-switch finger *D 2*, which is connected by the *D.-C.* segment to resistance tap *R 2*. One section of resistance, that between *R 1* and *R 2*, is thus cut out, since current can now flow directly from controller-drum finger *D 2* to the drum segment, to finger *A*, and then to the motors. From finger *T*, the path is: *T–a–D 5–D 5–R 5–R 5–R 4–R 3–R 2–R 2–D 2*–drum finger *D 2–A*–motors.

On the **third point**, fingers *D 3* and *b* cut out one more resistance section.

On the **fourth point**, fingers *D 4* and *A* cut out another section of resistance.

On the **fifth point**, the last resistance section is cut out, because current can flow from *T–a–D 5*–left-hand drum segment–*b–A*–to the motors. The motors are now in series across the line, without the starting resistance.

ALTERNATING-CURRENT CONTROL

68. The alternating-current main switch, Fig. 37, is closed by hand, thus exciting the compensator; current flows from the trolley through the alternating-current fuse, the alternating-current kicking coil, the alternating-current oil switch, and the compensator, to the ground. Both switches *R S* are thrown so that the left-hand blades connect *4* with *4 A*, and *4 A* with *4 B*. The commutating-switch fingers make contact with the alternating-current segments. The current for the retaining

coil of the main alternating-current oil switch is taken from the compensator tap *T3*. The path is: Tap *T3–T3* of left-hand set of commutating-switch fingers–*A.-C.* segments–*4–4–4 A–4 A–4 B–4 B*–retaining coil-ground at *G*.

69. On the **first point,** when the drum fingers first touch the drum segments, the path of the current from the low-voltage compensator tap *T1* is as follows: *T1–T1–A.-C.* segment–*D1–D1–S–S*–resistance section *SB*–separate blow-out coils–*A*–junction *C*. From this point the current divides, part of it passing through armatures Nos. *1* and *2* in series, and the rest of the current through armatures Nos. *3* and *4* in series. The currents join again at junction *d* and follow the path: reverse-switch finger *A A–F*–junction–*e*–through the four fields in parallel–junction *f*–reverse-switch finger *E–G*. The armatures are divided into two sets, which are in parallel, each set consisting of two armatures and their respective compensating coils in series. All of the fields are in parallel.

When the controller-drum movement to its first point is completed, the resistance section and the blow-out coils are cut out, and current flows from finger *D1* to *b*, to *A*, and thence to the motors. The resistance section *SB* is used in order to prevent short-circuiting a section of the compensator as the drum is turned from point to point. The separate blow-out coils and the resistance are thrown across the terminals of a section of the compensating coil during the transition period from point to point, and are cut out when the drum reaches its full position for any point. When the drum passes from the first point to the off-position on either direct- or alternating-current operation, the resistance *SB* and the blow-out coils are thrown in circuit; this reduces the current and at the same time blows out the arcs that may have formed at the ends of the drum segments.

70. On the **second point,** finger *D2*, Fig. 37, makes contact with its drum segment. Resistance *SB*, and the blow-out coils are cut in and then cut out of circuit, and, on the full point, current flows from tap *T2* on the compensator to *T2–D2–D2–A*, and thence to the motors.

On the **third point,** finger *D3*, which is connected to compensator tap *T3*, is thrown into action.

On the **fourth point,** finger *D4* and tap *T4* are active.

On the **fifth point,** finger *D5* and high-voltage motor tap *T5* are active, and the motors receive their maximum electromotive force.

OPERATION OF AUXILIARY APPARATUS

71. Each pair of motors is provided with a cut-out switch, by means of which either pair of motors may be cut out. On direct-current operation, the car lights, headlights, and heaters receive current through fingers *1* and *L & H* on the commutating switch. On alternating-current operation, they receive current through compensator tap *T6–T6–L & H.*

The air-compressor motor on direct-current operation receives current through finger *1* on the commutating switch–*3–3–3A–3A*–governor–*A5–AA5*–junction *g–F5–FF5–FF5–E5–E5–EE5–G.* The armature and all the field coils are in series.

The compressor motor on an alternating-current operation receives current through tap *T3–T3* of left-hand set of fingers on commutating switch–switch segments–*3–3–3A–3A*–governor–*A5–AA5*–junction *g* (here the current divides, one path leading through *F5* to ground, and the other through finger *AA5–E5–E5–EE5* to ground at *G.* The sections of field coils *g–F5*, and *E5–EE5* are in parallel.

SPRAGUE-GENERAL ELECTRIC MULTIPLE-UNIT SYSTEM

C-40-A CONTROLLER FOR ALTERNATING-CURRENT CONTROL

72. The type C-40-A controller is shown in Fig. 38 (*a*). The segments opposite the eight lower fingers [*b* to *6*, Fig. 38 (*b*)] constitute the accelerating section of the drum; the power section takes in the two segments opposite the

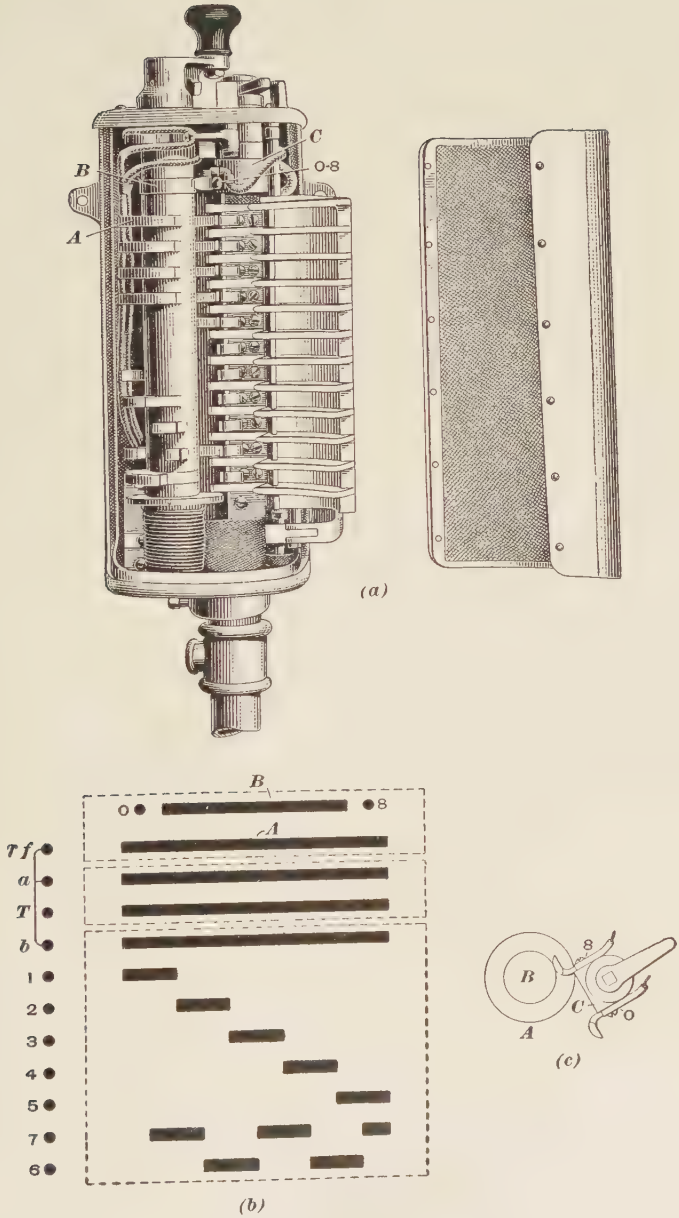


FIG. 38

fingers *T* and *a*; and the reverse section consists of segment *A* opposite finger *rf*, and segment *B* opposite either finger *0* or *8*. Segments *A* and *B* are electrically connected and receive current through finger *rf*. The reverse fingers *0* and *8* (one directly behind the other) are mechanically connected to the reverse cylinder *C*, Fig. 38 (*a*). Either one of the fingers *0* or *8* may be connected to drum segment *B* by throwing the reverse handle either to the forward or to the reverse position, as indicated in Fig. 38 (*c*). For the forward position, finger *8* is active, and for reverse position, finger *0* is active. The coiled spring at the bottom of the case, Fig. 38 (*a*), serves to return the controller handle to off-position in case of emergency.

C-40-A CAR-WIRING DIAGRAM

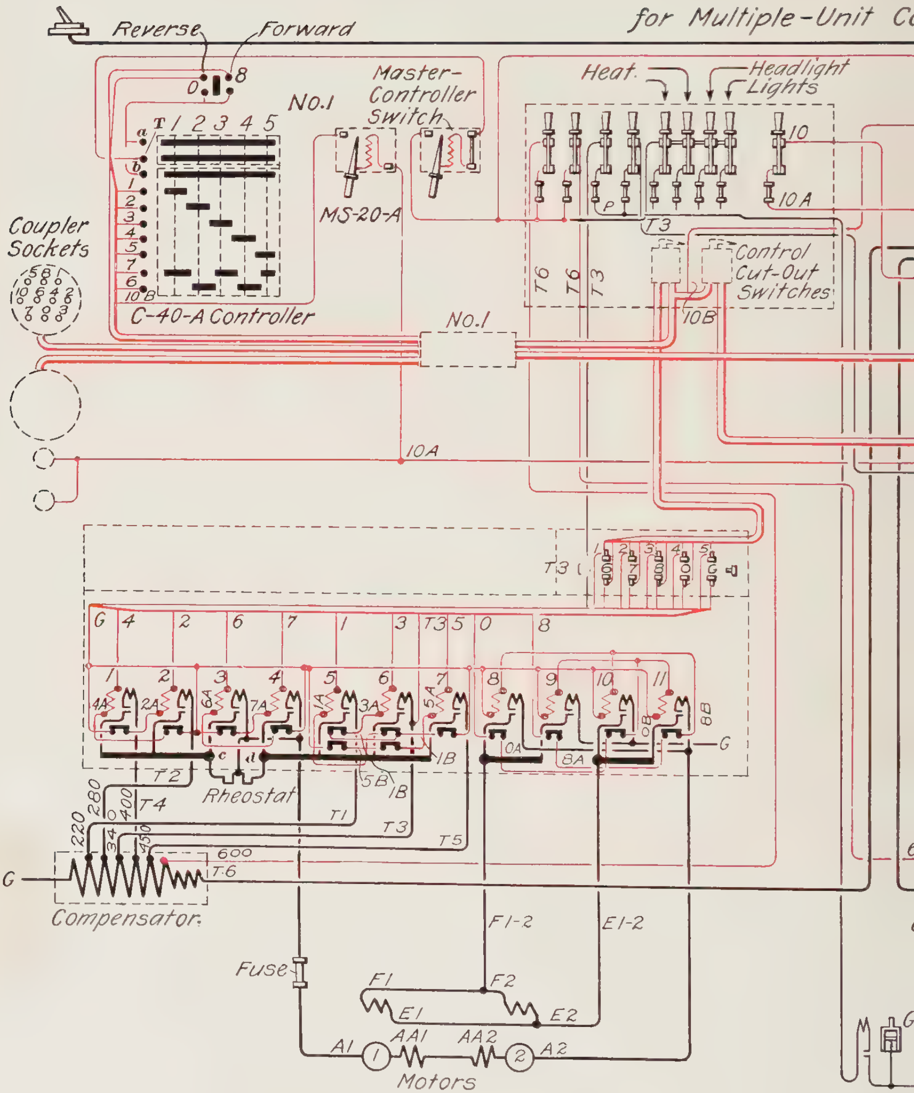
73. A car-wiring diagram for the alternating-current operation of two C-40-A master controllers connected to four motors is shown in Fig. 39. The system is duplex; that is, the control circuit, the compensator, and the contactors are distinct with each pair of motors.

A small autotransformer, which is shown near the oil switch, provides current for the operating coil of the switch. One end of the secondary coil of this transformer is grounded near the transformer, and the other end is grounded through *10–10 A–10 A–10 A*–switch–*10 B–10 B–10 B*–operating coil–*G*. When switch *10–10A* is closed, the operating coil of the oil switch closes the oil switch, and currents flow through the two compensators to ground. When the oil switch closes, the interlock under it opens, and the operating coil is now grounded through six high-resistance tubes. Just sufficient current flows to allow the operating coil to retain the switch in its closed position and yet not cause heating of the coil.

Wires are numbered or lettered alike at points where they enter and leave the cable hose. The action of controller No. *1* will be considered with the reverse cylinder, located at the top of the controller, at forward position; that is, with finger *8* in contact with its segment. The currents for the control

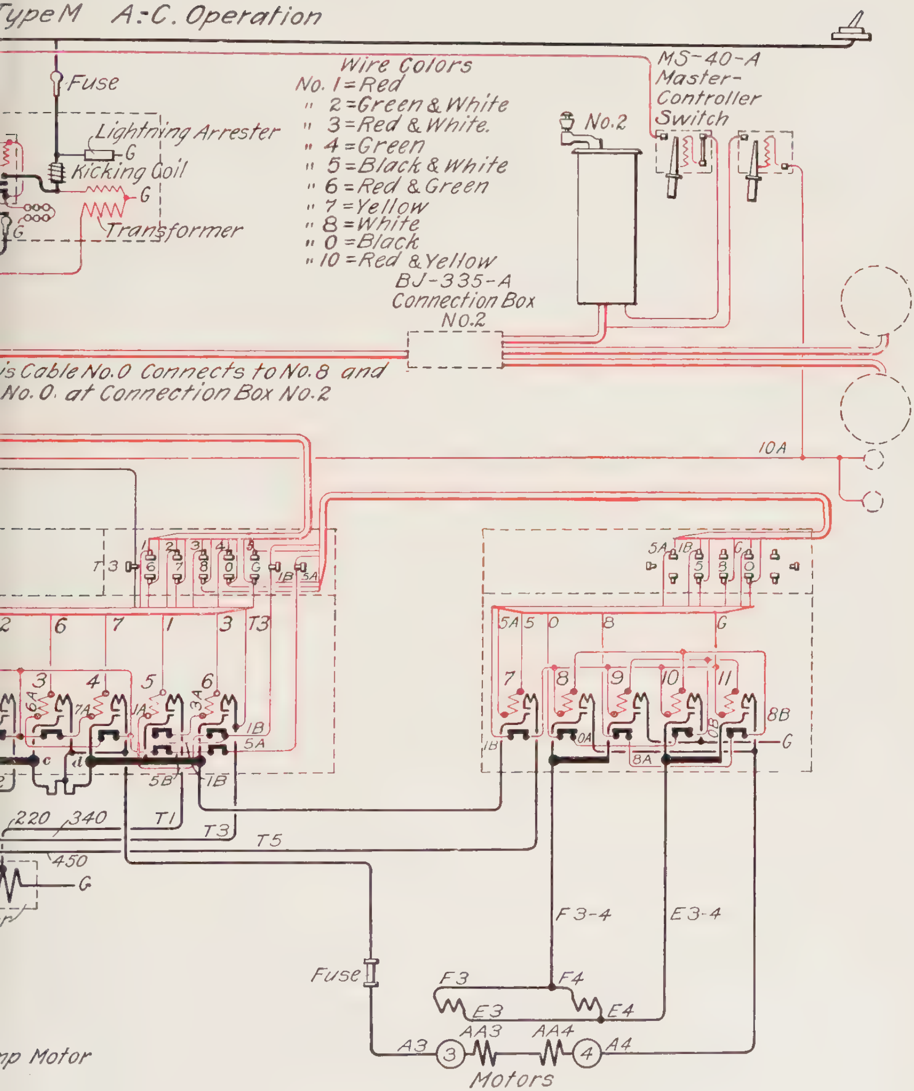
CAR-

for Multiple-Unit C



DIAGRAM

Type M A-C. Operation



circuits are obtained from taps *6* of the two compensators through the two knife switches shown at the left of the group of switches. The wires of the control circuit are indicated by red lines, and the wires of the power circuit, by black lines.

74. First Point.—On the first point, current flows from the master-controller switch to finger *T*, thence to the two drum segments, finger *a*, and to the lower right-hand finger of the reverse cylinder. Two lower reverse-cylinder fingers are shown in Fig. 39, but in the actual controller only one finger *rf*, Fig. 38 (*a*), is employed. From the reverse cylinder, Fig. 39, the current path for the control of one set of motors is as follows: Finger *8*–wire *8*–connection box No. *1*–cut-out switch–*8*–*8*–interlock below the operating coil of contactor *9*–*8 A*–interlock below the operating coil of contactor *11*–*8 B*–operating coils of contactors *8* and *10* in parallel, and thence to the common ground wire *G*.

From finger *a*, current also flows to finger *b*–finger *1*–connection box No. *1*–cut-out switch–*1*–*1*–operating coil of contactor *5*–*1 A*–upper interlock of switch *6*–*1 B*–interlock of switch *7*–*G*. From finger *7*, current flows through connecting box No. *1*–*7*–*7*–operating coil of contactor *4*–*7 A*–interlock of switch *3*–ground wire *G*. The main switches *4*, *5*, *8*, and *10* are closed by the action of their operating coils. Compensator tap *T 1* is connected to contactor *5*.

In Fig. 40, the paths of the currents in the control circuit are indicated by red lines, while the path of the current in the power circuit for a set of two motors is indicated by black lines.

The two motor armatures are permanently connected in series, the compensating motor windings are connected directly in series with the armatures, and the fields of the two motors are connected in parallel. As the controller is operated, the same action is taking place in the one set of motors as in the other.

75. First Intermediate Position.—Soon after leaving the first point, Fig. 39, finger *1* drops contact, and at the

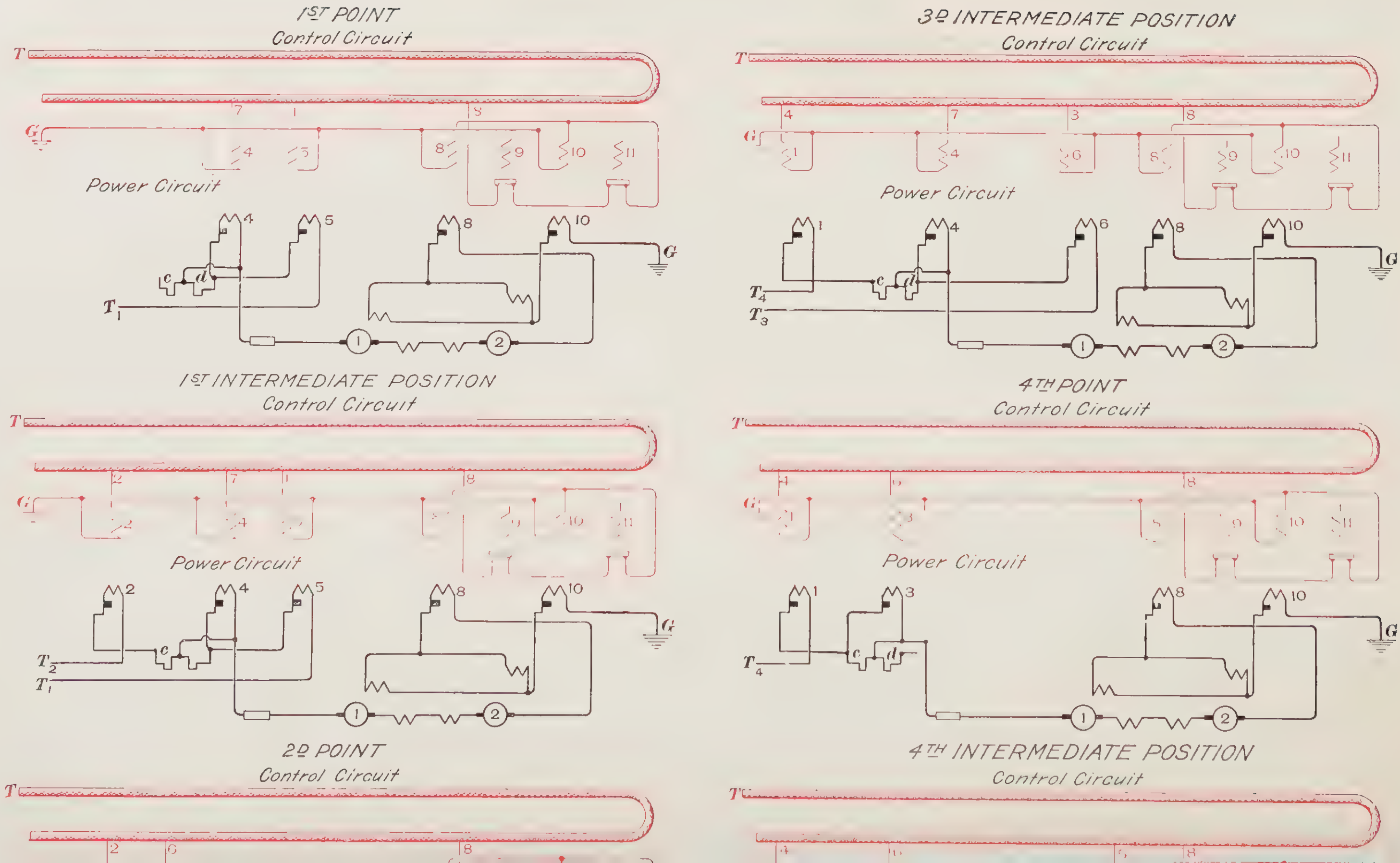
same time finger *2* makes contact. When fingers *1*, *2*, and *7* are all active for an instant, contactors *5*, *2*, and *4* are closed. The motors are still connected to tap *T1* by contactors *5* and *4*, but taps *T1* and *T2* are bridged by section *c* of the rheostat. When finger *1* drops its contact, contactor *5* opens, thus cutting out tap *T1*, and allowing all the current to flow through the tap *T2*–contactor *2*–section *c* of the rheostat–contactor *4* and wire from the center of the rheostat, to motors.

76. Second Point.—Finger *7* drops contact, and finger *6* makes contact with the drum segments. Contactor *4* opens and contactor *3* closes, thus cutting out section *c* of the rheostat. The motors are now connected directly to tap *T2*.

77. Second Intermediate Position.—Finger *2* drops contact, and finger *3* makes contact. Contactor *2* opens, and contactor *6* closes. At the instant when both contactors *2* and *6* are closed, section *d* of the rheostat is bridged across taps *T3* and *T2*. When contactor *2* opens, all of the current flows from tap *T3* through section *d* of the rheostat to the motors.

78. Third Point.—Finger *6* drops contact, and finger *7* makes contact. Contactor *3* opens and contactor *4* closes, thus short-circuiting resistance section *d* and leaving the motors connected directly to tap *T3*.

79. Remaining Points.—The connections of the devices in the control circuits and the motor connections for the remaining points and intermediate positions are shown in Fig. 40. When moving through the intermediate positions, a rheostat section is shunted across two compensator taps; then, the lower voltage tap is dropped, and the resistance section is left in circuit. Finally, this resistance is short-circuited, and the motors are left connected directly to the high-voltage tap, when the controller movement to a full point is completed. On the **fifth point**, the maximum voltage is impressed on the motors, as motor tap *T5* is active.



1ST POINT
Control Circuit
Power Circuit
T
G
T1
3D INTERMEDIATE POSITION
Control Circuit
Power Circuit
T4
T3
1ST INTERMEDIATE POSITION
Control Circuit
Power Circuit
T2
T1
4TH POINT
Control Circuit
Power Circuit
T4
2D POINT
Control Circuit
4TH INTERMEDIATE POSITION
Control Circuit

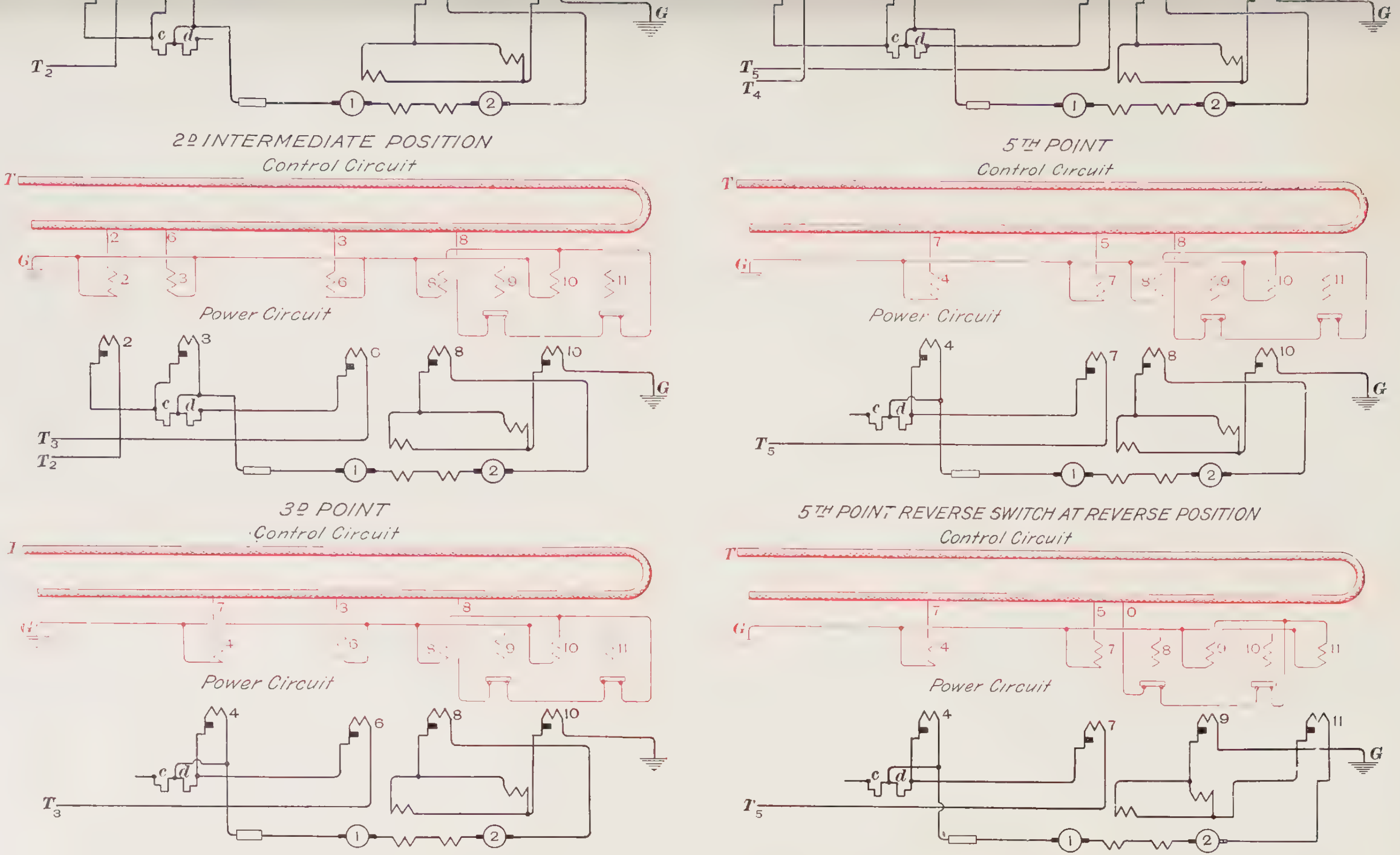

2D INTERMEDIATE POSITION
Control Circuit
Power Circuit
5TH POINT
Control Circuit
Power Circuit
3D POINT
Control Circuit
Power Circuit
5TH POINT REVERSE SWITCH AT REVERSE POSITION
Control Circuit
Power Circuit

FIG. 40

80. Operation of Reverse Cylinder.—When the

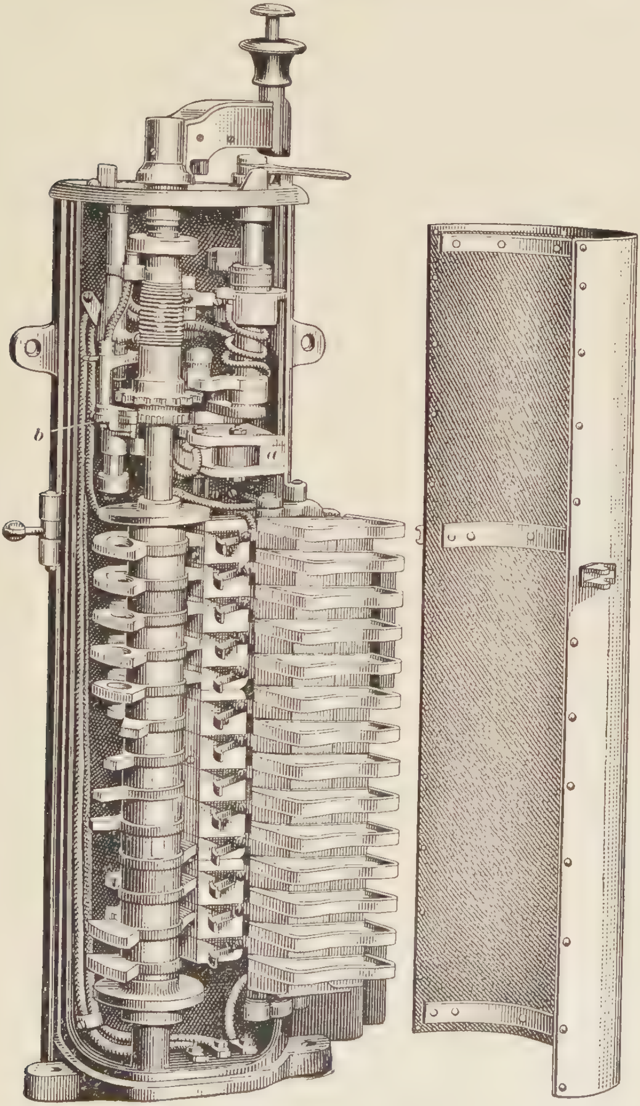


Fig. 41

reverse cylinder on the master controller, Fig. 39, is thrown

to the reverse position, contactors *8* and *10* are opened, and the lower left-hand reverse-switch finger is connected to finger *0*–wire *0*–connection box No. *1–0–0*–interlock below the operating coil of contactor *8–0 A*–interlock of switch *10–0 B*–operating coils *9* and *11* in parallel–*G*. Contactors *9* and *11* are closed. The connections of the armatures remain unchanged, but the field connections have been reversed, as is shown by the fifth reverse point, Fig. 40. Motor rotation is therefore reversed.

C-47 CONTROLLER FOR ALTERNATING-CURRENT AND DIRECT-CURRENT CONTROL

81. In Fig. 41 is shown a **C-47 master controller.** This controller has auxiliary contacts *a* that open the control circuit in case the knob on the controller handle is released. A trip lever *b* is also provided. This lever will open the auxiliary contacts when the handle is moved toward the off-position. The handle must be returned to off-position before the controller can be operated to again pick up the contactors.

C-47 CAR-WIRING DIAGRAM

82. A car-wiring diagram of two C-47 controllers connected to four motors, for operation by direct or by alternating current, is shown in Fig. 42. When direct current is to be used, the direct-current switch is automatically closed by the operating coil on the switch. Direct current flows from the trolley, through the kicking coil–primary coil *p*–operating coil of the *D.-C.* switch–interlock, which is closed when the *D.-C.* switch is open, to the ground at *G*. As the switch closes, the ground connection at the interlock is broken, and current now flows to ground through the four high-resistance tubes. The reduced current prevents heating and is sufficient to retain the switch in its closed position. The direct current flowing through primary coil *p* has no effect on the secondary coil *s* and the operating coil of the alternating-current switch. If the line electromotive force

CAR-W

for Multiple-Unit Co

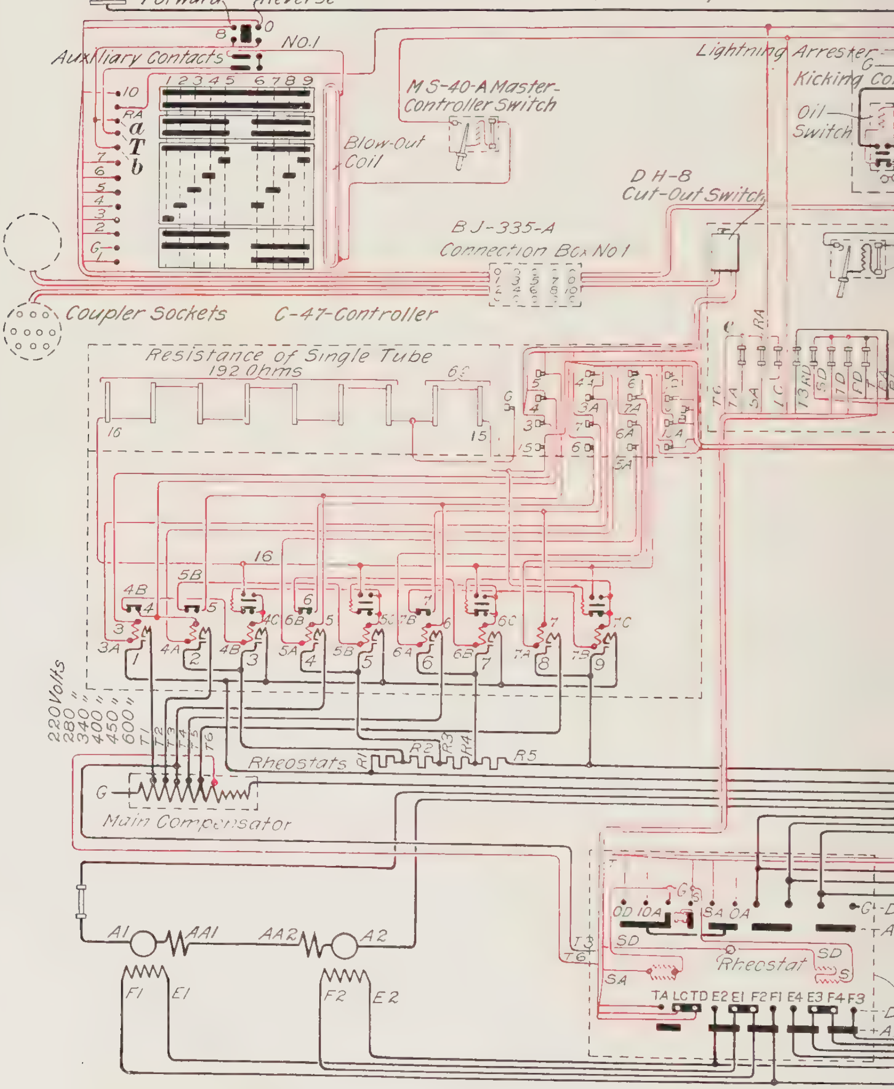
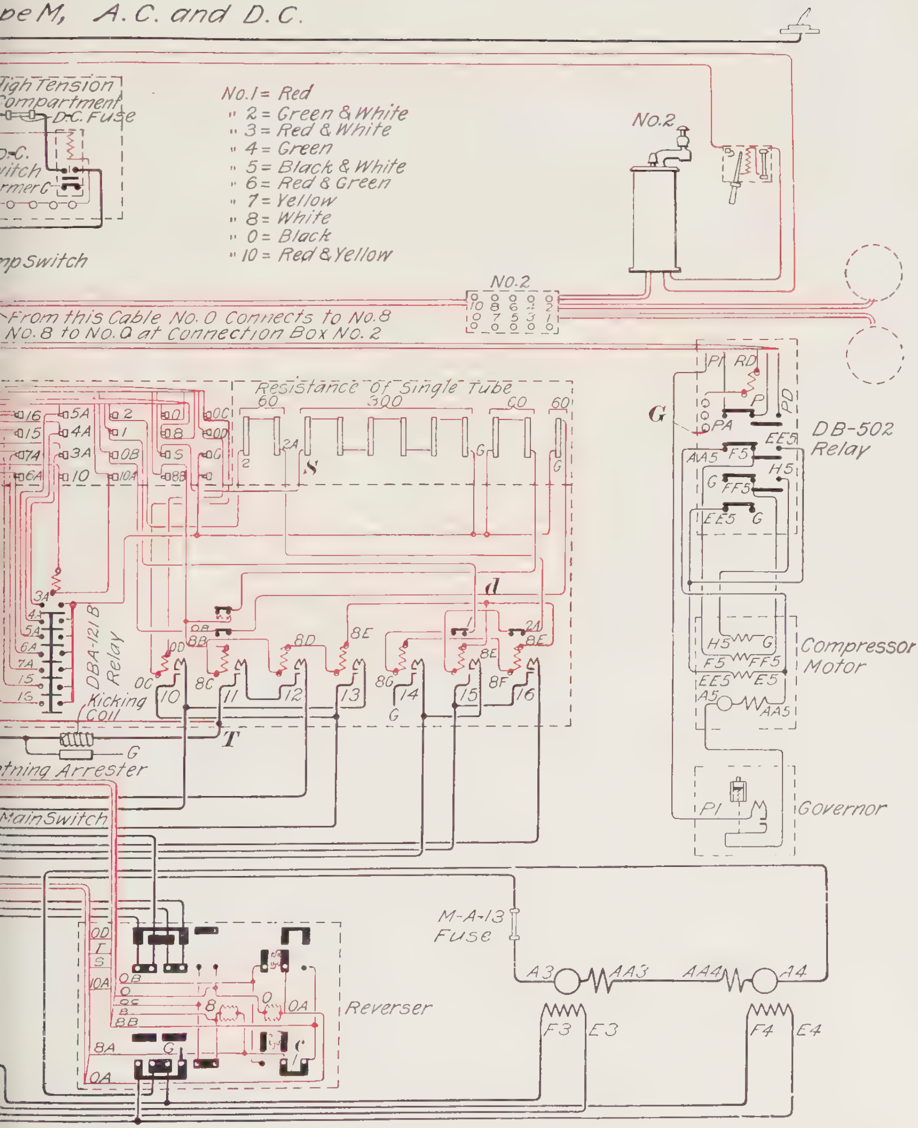


DIAGRAM
pe M, A.C. and D.C.



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becomes very low, the operating coil releases and opens the direct-current switch.

Current for the control circuit of the commutating switch flows from the trolley–*D.-C.* fuse–*D.-C.* switch–*D.-C.* kicking coil–junction *T* near lower connection of contactor *11–T–T* near reverser–*T* near commutating switch–up through cable–*T–S D–S D*–rheostat–*S D–D.-C.* operating coil of the commutating switch–*S–S*– to ground through the *A.-C.* commutating-switch segments and finger *G*, if the commutating switch rests in the *A.-C.* position. If the switch is in the *D.-C.* position, the path to ground is from *S* finger of the commutating switch–*S–S–S*–six high-resistance coils–*G*. The commutating switch is thrown to its direct-current position.

Current for the master controller flows from the lower portion of contactor *11–T–T–T*–up through cable–*T–T D–T D –D.-C.* segment–*L C–L C*–master-controller switch–blow-out coil–auxiliary contacts–finger *T*.

83. Direct-Current Operation.—When using the C-47 controller for direct-current operation, all of the nine controller points are employed.

From finger *T* on the **first point,** current flows along the following path: Finger *T*–drum segments–*a*–forward finger *8* on reverse cylinder–*8* on connection box No. *1–8–8 8–8*–forward operating coil of the reverser, thus throwing the reverser to forward position if it was at the other position–fingers on segment *c–8 B–8 B*–the current divides, part of it flows through the upper interlock over contactor *11*–two resistance tubes–*G*, and part through *8B*–operating coil of contactor *11*, which opens the interlocks above it, thus interrupting the first path to ground–*8 C*–operating coil of contactor *12–8 D*–operating coil of contactor *13–8 E–d–8 E* –operating coil of contactor *15*–interlock over contactor *16–2 A–2 A*–two high-resistance coils–*2–2–2–2* on connection box No. *1*–finger *2* on the master controller–ground at finger *G*.

From point *d* current cannot flow through the operating coils of contactors *16* and *11*, as finger *1* on the controller

hangs in the air; also, the interlock over contactor *15* opens when contactor *15* closes. The reverser is thrown to its forward position, and contactors *11*, *12*, *13*, and *15* are closed.

The operating coil of the relay is connected to controller finger *10*, which is active only for alternating current. Thus, the relay is open when direct current is used, so no current can flow from finger *T–a–b–3–3* on connection box No. *1–3–3*–operating coil of contactor *1–3 A–3 A–3 A*–finger *3A* of relay, because of the open circuit at the relay. The connections of the operating coils, the contactors, and the motors are shown in Fig. 43.

On the **second point,** finger *4*, Fig. 42, makes contact with its drum segment. The current path is finger *4–4* on connection box No. *1–4–4* (current cannot flow to the right because of the open circuit at the relay)–interlock over contactor *1–4 B–4 B*–operating coil of contactor *3–4 C*–at first lower interlock of switch *3*–interlocks of switches *5*, *7*, and *9* to *15*–two resistance tubes to ground, and then an instant later to ground by the upper interlock over contactor *3* when contactor *3* closes–*16*–seven resistance coils–*G*.

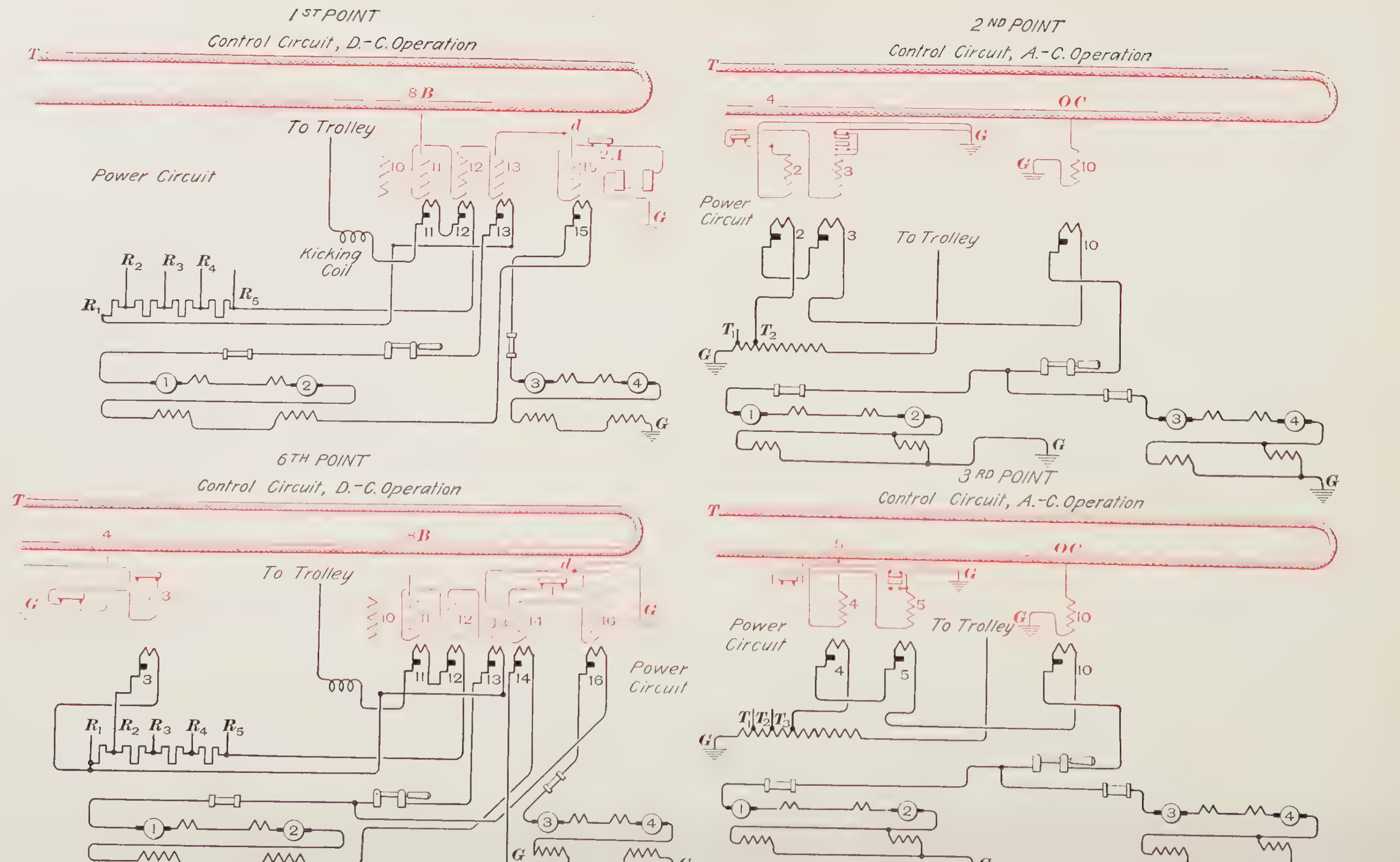
Contactor *3* is closed, and the rest of the contactors remain as before. Current can now flow from resistance lead *R 2*, through contactor *3*, to the main motor switch. The section of resistance between *R 1* and *R 2* is cut out.

On the **third point,** finger *5* makes contact with its drum segment. Contactor *5* is closed, and resistance sections *R 1–R 2* and *R 2–R 3* are cut out.

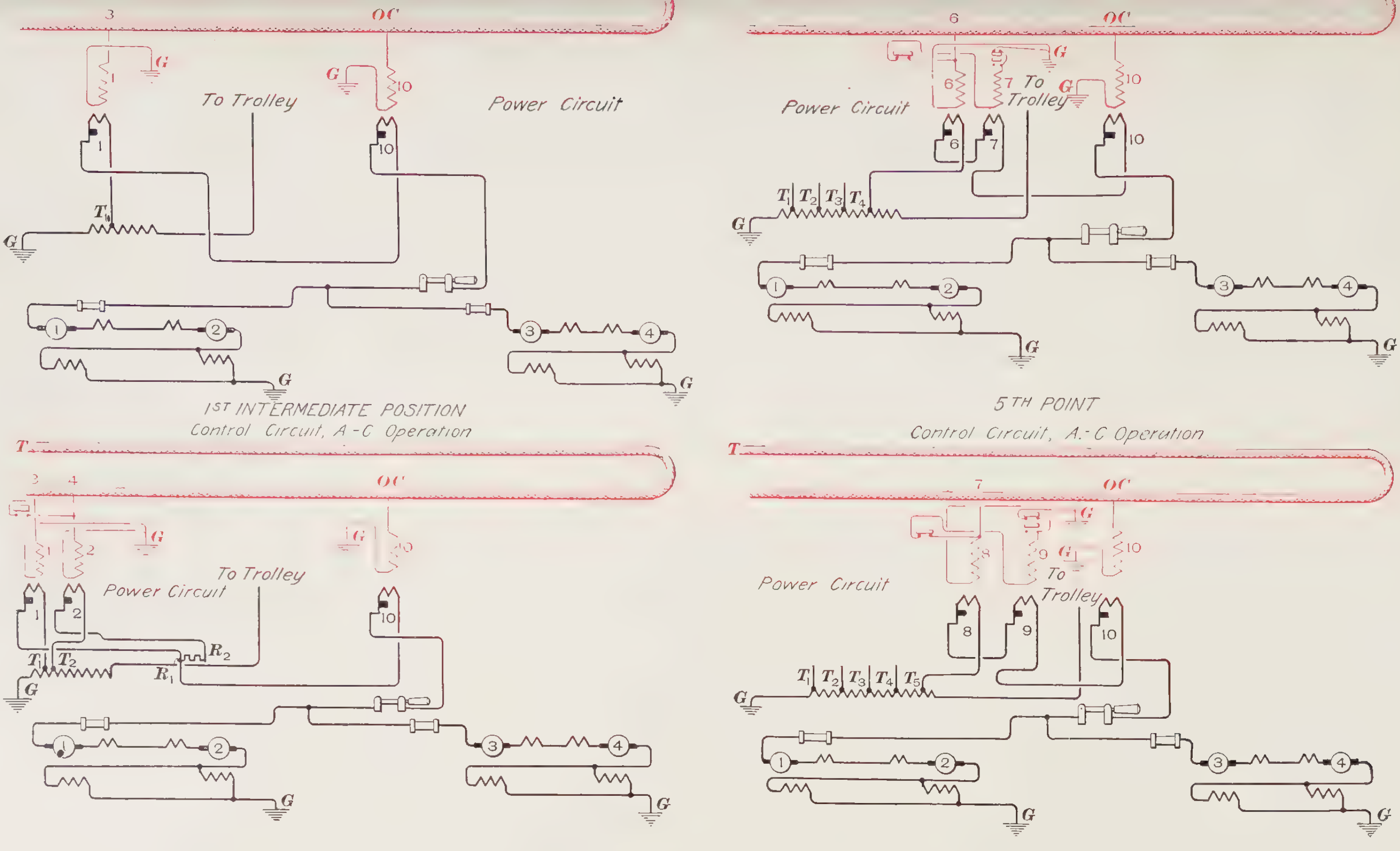
On the **fourth point,** finger *6* makes contact with the drum segment. Contactor *7* is closed. Resistance sections from *R 1* to *R 4* are cut out.

On the **fifth point,** finger *7* becomes active, and contactor *9* closes. All the resistance sections are cut out, and the motors are in series across the line.

On the **sixth point,** finger *2* drops its contact, and finger *1* makes contact with its drum segment. Contactor *15* and its interlock open. Current flows from finger *T* on the controller to junction *d*, over contactor *15*, by the same



1ST POINT
Control Circuit, D.-C. Operation
To Trolley
Power Circuit
Kicking Coil
R_1 R_2 R_3 R_4 R_5
2ND POINT
Control Circuit, A.-C. Operation
Power Circuit
To Trolley
T_1 T_2
6TH POINT
Control Circuit, D.-C. Operation
To Trolley
Power Circuit
R_1 R_2 R_3 R_4 R_5
3RD POINT
Control Circuit, A.-C. Operation
Power Circuit
To Trolley
T_1 T_2 T_3



1ST INTERMEDIATE POSITION
Control Circuit, A-C Operation
5TH POINT
Control Circuit, A.-C Operation
Power Circuit
To Trolley
OC
T
G
51 26874

FIG. 42

path traced for the first point. From point *d*, near contactor *15*, current now flows to *8 E*–operating coil of contactor *16*–*8 F*–operating coil of contactor *14*–*8 G*–interlock *1–1–1–1* on connection box No. *1*–finger *1*–drum segment–*G*. Current cannot flow from *d* through the operating coil of contactor *15*, because finger *2* hangs in the air and interlock *2 A* is open.

Contactors *14* and *16* are closed, and contactor *15* is opened. Finger *4* is active, and contactor *3* is closed. The two sets of motors are in parallel with three sections of resistance in series with them, as indicated in Fig. 43.

On the **seventh, eighth,** and **ninth points,** one section of resistance, Fig. 42, is cut out on each point in the same manner as on the third, fourth, and fifth points. On the ninth point, the two sets of motors are in parallel across the line, without any resistance sections in series.

84. Alternating-Current Operation.—When using the C-47 controller for alternating-current operation, the first five controller points are employed.

On the **first point,** the alternating-current oil switch is automatically closed by the operating coil on the switch. The direct-current switch is opened automatically as the trolley passes over the line breaker separating the alternating-current and direct-current line wires. The direct-current switch interlock is closed, and an alternating current at a pressure of about 3,300 volts flows through the primary coil *p*, the operating coil of the direct-current switch, directly to ground through the direct-current interlock. The alternating current in *p* sets up an alternating current in *s* and in the operating coil of the alternating-current switch. The resistance and the impedance of the operating-coil circuits are so adjusted that the system is selective. The direct-current switch is thrown in when the trolley is on the direct-current wire, and the alternating-current switch is thrown in when the trolley is on the alternating-current trolley wire. When the alternating-current interlock opens, a resistance is introduced into the secondary circuit to

prevent the operating coil from heating. Current flows from the trolley–kicking coil–*A.-C.* oil switch–main compensator to ground at *G*.

From compensator tap *T6*, current flows to *T6–T6*–point *e* –*S A–S A–A.-C.* operating coil of the commutating switch –ground at *G*. The commutating switch is thrown so that the fingers make contacts with the alternating-current segments.

At point *e*, current flows to *T A–T A–A.-C.* segment of commutating switch–*L C–L C*–master-controller switch–blow-out coil–auxiliary contacts–finger *T*.

From *e*, current also flows to *R A* and to controller-drum finger *R A*. From this finger, the path of the current, when the controller drum is active, is as follows: *R A–10–10* on connection box No. *1–10 A–10*–operating coil of the relay–*10A–10 A–10 A–A.-C.* segment of commutating switch–*G*. The relay rises, and its metal portions make contacts with all of its fingers. The fingers on the right side of the relay are connected to the ground, so that all the other fingers have a ground connection when the relay is active. Current from finger *T* flows to finger *8* on the controller reverse switch–*8* on the reverser–reverser segment–*0 C–0 C–0 C*–operating coil of contactor *10–0 D–0 D–0 D–0 D–G*. Contactor *10* closes.

From *8* on the reverser, another path is as follows: *8*–forward reverser coil–*8 A*–finger *8 A* on the commutating switch–*A.-C.* segments–ground. The path through segment *c–8 B*–operating coils of contactors *11*, *12*, *13*, and *15* is short-circuited by the path through *8A*; therefore, contactors *11*, *12*, *13*, and *15* open. The reverser is still at forward position. Another path from finger *T* on the master controller, when the drum is at the first point, is: *T–a–b–3–3* on connection box No. *1–3–3*–operating coil of contactor *1–3 A–3 A–3 A–3 A*–relay–*G*.

Contactor *1* closes. The sets of motors are connected in parallel by means of the alternating-current segments of the commutating switch. The main field coils of each pair of motors are connected in parallel, but the two armatures are

connected in series. The connections of the control and power circuits are shown in Fig. 43, at the first point, alternating-current operation.

On the **first intermediate position,** before controller finger *3*, Fig. 42, breaks contact with its drum segment, finger *4* makes contact with its segment. As contactor *1* is still closed at the intermediate position, its interlock is open. Current flows from finger *4* to point *4* between contactors *1* and *2*. Current cannot flow to the left because of the open interlock, but it can flow through the operating coil of contactor *2* to the ground through the relay.

Contactor *2* closes, and the first resistance section is shunted across compensator taps *T1* and *T2*, as indicated in Fig. 43, at the first intermediate position. The motor circuit is connected to side *T1* of the resistance section.

On the **second point,** as soon as controller finger *3*, Fig. 42, drops its drum contact, contactor *1* opens and its interlock closes. Current now flows from point *4* to the left, through the interlock of contactor *1*, and then through the operating coil of contactor *3* to the ground, first by way of the lower interlock–wire *15*–relay–ground, and shortly after by way of the upper interlock–wire *16*–relay–ground. These circuits are now grounded through the alternating-current relay, since that path offers less resistance than the path through the high-resistance tubes.

Contactor *1* opens just before contactor *3* closes, due to the interlock over contactor *1*. For a short time, current flows from *T2* through the first section of resistance to the motor circuit. Immediately after, contactor *3* closes and a direct path is provided to the main motor switch, thus short-circuiting the resistance section. This condition is indicated in Fig. 43 at the second point.

On the **third, fourth,** and **fifth points,** Fig. 42, higher-voltage taps are successively connected to the motor circuit. During the passage of the controller drum through the intermediate positions, the different sections of the main resistance coil are used to shunt sections of the compensator in a similar manner to that described in connection with the first

intermediate position. On the fifth point, contactors *8*, *9*, and *10* are closed, and the two sets of motors in parallel are connected between the high-voltage tap *T5* and the ground. The controller should not be advanced beyond the fifth point for alternating-current operation.

85. Operation of the Compressor Motor.—With direct-current operation, current flows through control wire *T*, Fig. 42–*R D*–*R D*–operating coil of the compressor-motor relay–three high-resistance coils, to ground at *G*. The segments of the compressor-motor relay are lifted. Current flows from *T* through *P D*–*P D*–*P*–*P*–pump switch, and through the armature and all the main field coils in series to ground. When using alternating current, the compressor-motor relay segments are in their lower positions. Current is obtained from tap *T3*. The two lower portions of the field windings are in parallel, and the upper field-winding section is cut out.

AUXILIARY APPARATUS AND EQUIPMENT

CURRENT COLLECTORS

86. In high-speed railway work, it is essential that the current-collecting device should always remain in contact with the trolley wire while the car is in action. If the current collector should leave the trolley wire while the car is moving at a high speed, great damage to the overhead work would probably ensue. The liability of such an accident occurring has been reduced by the improved system of overhead line construction and the new forms of current-collecting devices.

PANTAGRAPH TROLLEY

87. Description. A type of **pantagraph trolley** is shown in Fig. 44. The trolley is secured to the top of the car by the feet *a*, which are insulated from the other parts of the trolley by the massive insulators *b*. The main

operating cylinder is shown at *c*, and a latch cylinder at *d*. A hook *e* on the lower side of contact shoe *f* engages with the

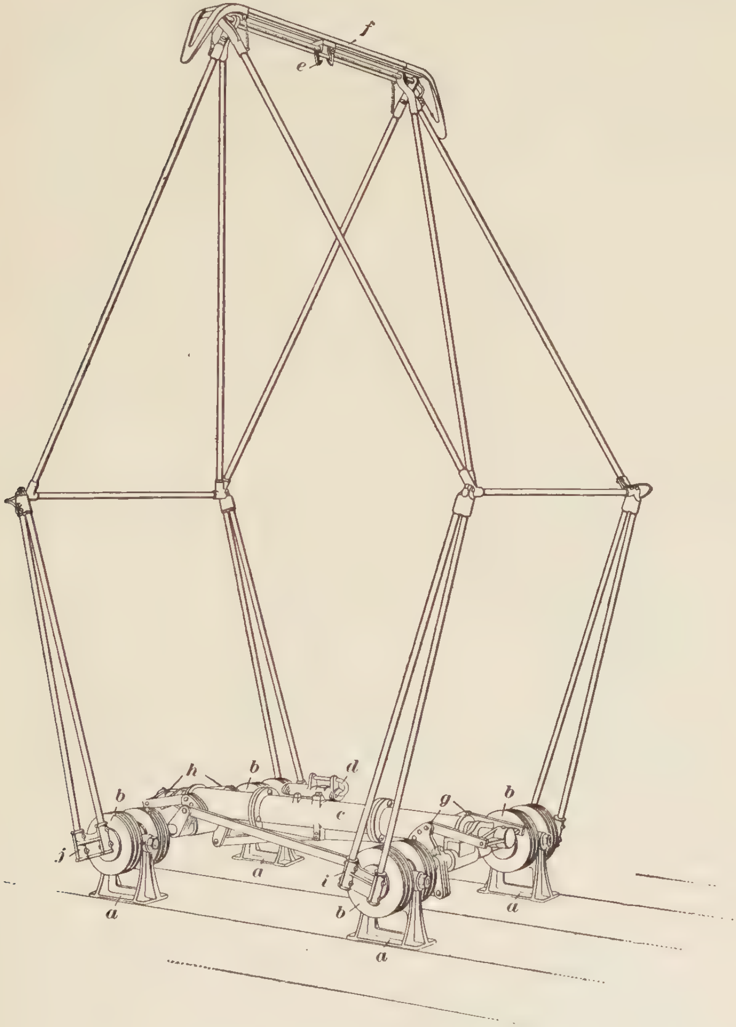


FIG. 44

latch when the trolley is in its lowered position, as indicated in Fig. 45. The steel contact shoe is broad, so as to have

a large surface in contact with the wire, and it is customary to stagger the trolley wire slightly so that the wear on the conducting surface of the shoe will be distributed. Grease

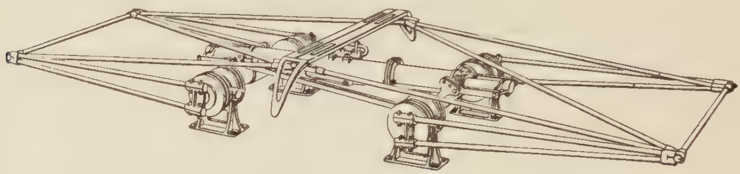


FIG. 45

is used on the shoe, and the wear on the wire is slight. The shoe is so long that it is impossible for it to leave the wire under normal conditions.

88. Operation.—The pantagraph is operated by means of compressed air. Pipes connect to the main cylinder and to the latch cylinder, as indicated in Fig. 33. The pantagraph is normally held in a raised position against the wire by compression springs *k*, *k*, Fig. 46 (*a*). These springs force piston rods *l*, *l* and pistons *m*, *m* toward the center of

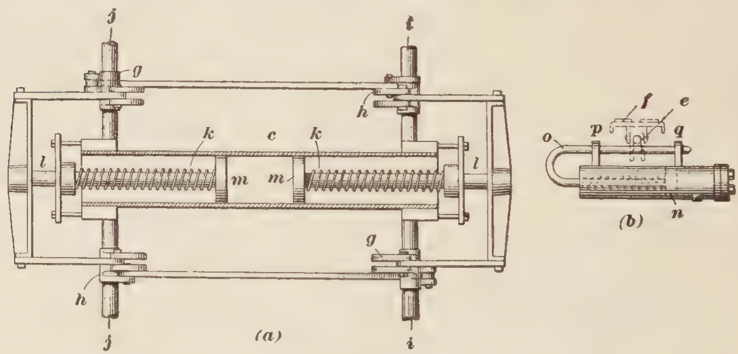


FIG. 46

main cylinder, thus causing short levers *g*, *g* and shaft *i*, Figs. 44 and 46 (*a*), to rotate in a counter-clockwise direction, when viewed from the left side of Fig. 44 and the front of Fig. 46 (*a*), and levers *h*, *h* and shaft *j* to rotate in a clockwise direction. The arms attached to the shafts are forced upwards, and the shoe is pressed against the trolley wire.

In order to lower the trolley, compressed air is allowed to flow into the center of the main cylinder. The pistons *m*, *m*, Fig. 46 (*a*), are forced outwards, shaft *i*, Figs. 44 and 46 (*a*), rotated in a clockwise direction, shaft *j* rotated in a counter-clockwise direction, and the trolley lowered to the position shown in Fig. 45. Compressed air is admitted to the latch cylinder when the trolley is nearly at its lowest

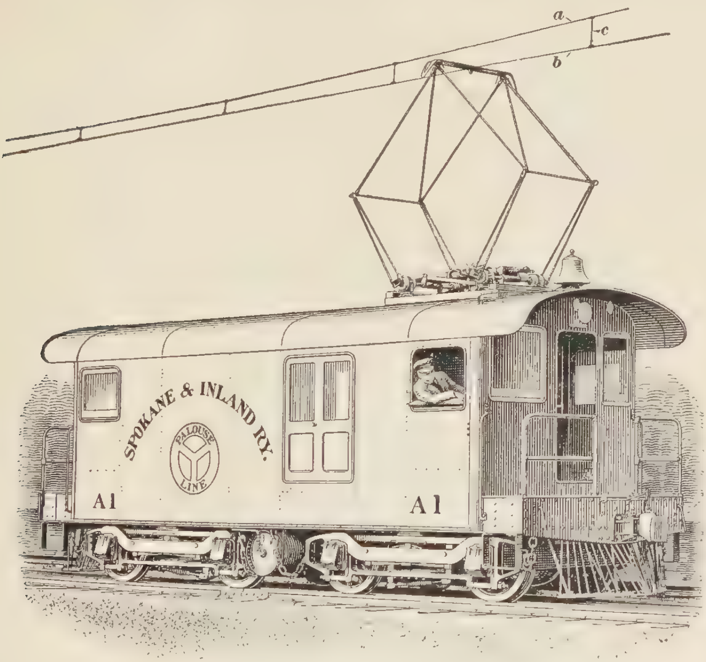


FIG. 47

position. Piston *n*, Fig. 46 (*b*), of the latch cylinder is moved toward the left, moving latch *o* out from between lugs *p* and *q* and allowing hook *e*, Figs. 44 and 46 (*b*), to fall into place between *p* and *q*. Cutting off the air from the latch cylinder allows a spring in the cylinder to snap the latch *o* through *p*, *e*, and *q*. The air is then released from the main cylinder, and the latch holds the trolley down.

When it is desired to raise the trolley, air is momentarily admitted into the main cylinder, where it flows into the latch cylinder through a small hole between the cylinders. The latch is released, and the main-cylinder springs raise the trolley. The small amount of air that was admitted to the center of the main cylinder acts as a buffer, thus preventing too sudden action of the springs. In Fig. 47 is shown an electric locomotive provided with a pantagraph trolley.

BOW TROLLEY

89. The **bow type of trolley** is shown in Fig. 48. This trolley is raised and lowered by compressed air, under

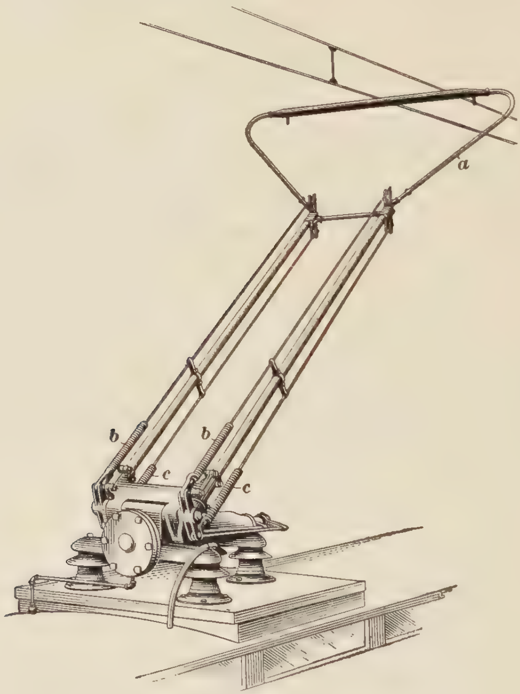


Fig. 48

the control of the motorman. The upper bow portion *a* of the trolley assumes a nearly vertical position, and has

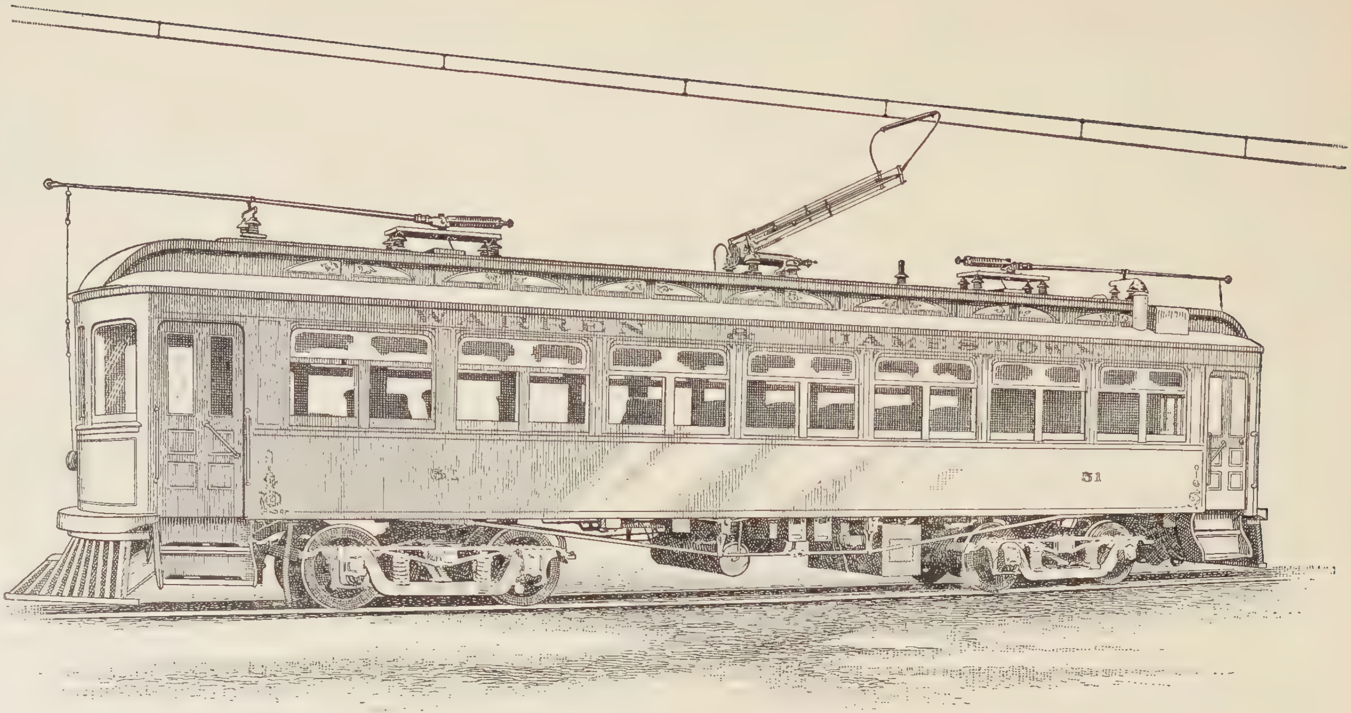


FIG. 49

freedom of movement independent of the two main trolley poles. The movement is controlled by the springs *b, b* and *c, c*. The pair of springs *b, b* keeps the sliding contact shoe against the trolley wire when the car is moving in one direction, and the other pair of springs *c, c* serves the same purpose when the car is moving in the opposite direction. The main portion of the trolley remains in the same position for either direction of car movement. The bow portion, however, inclines slightly in a direction opposite to the direction in which the car moves. An electric car equipped with a bow trolley is shown in Fig. 49.

LINE CONSTRUCTION

90. For high-speed, high-potential railway work, the ordinary overhead construction is not suitable. In such construction, the trolley wire sags between supports, and would thus cause sudden lifting and bending of the wire as the trolley passed under it. The insulation of the 500- or 600-volt line construction is insufficient for the high voltages used in alternating-current railway work. To meet such conditions and to provide an overhead system that fulfils the requirements of high-speed railroading, the *catenary line-construction system* was introduced.

SINGLE CATENARY

91. In the **single-catenary construction**, shown in Figs. 47 and 49, a $\frac{7}{16}$-inch, seven stranded, galvanized-steel cable, *a* Fig. 47, called a *messenger cable*, is supported by bracket construction from poles on one side of the track or from span wires between poles on opposite sides of the track. The trolley wire *b* is suspended from the messenger cable by means of iron hangers *c* of proper lengths to maintain the wire at a uniform height above the track. The contact shoe thus slides smoothly under the wire and will cause it to move but slightly. The messenger cable, being connected electrically as well as mechanically to the trolley wire, serves

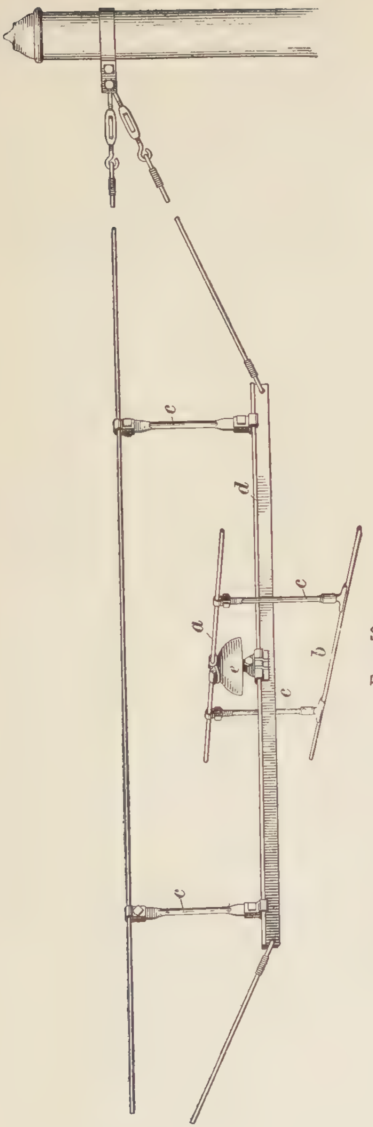


Fig. 50

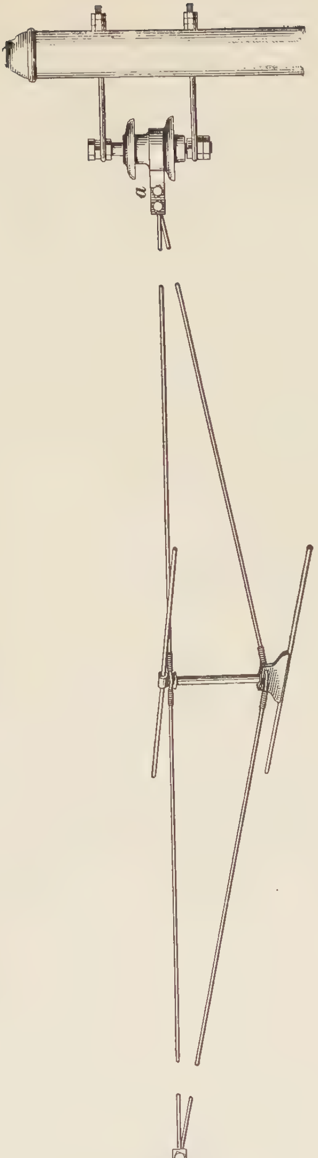


Fig. 51

as an auxiliary conductor. Both the cable and the trolley wire are insulated from the brackets and poles by porcelain or wooden insulators.

92. A cross-span, single-catenary construction for a straight track is shown in Fig. 50, where *a* is the messenger

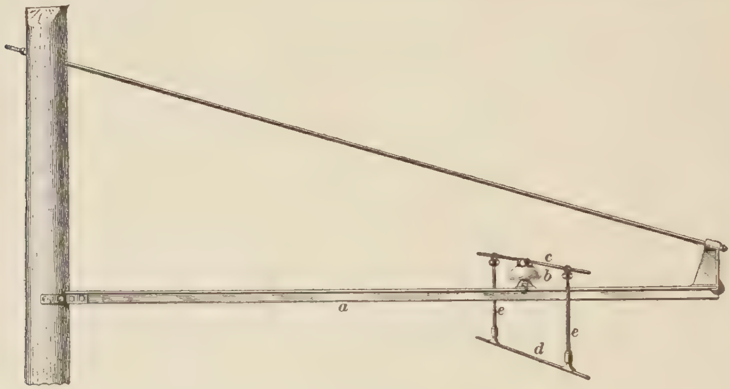


FIG. 52

cable; *b*, the trolley wire; *c*, hangers; *d*, a **T** iron; and *e*, a large, porcelain insulator clamped to *d*. The messenger cable is fastened to *e* by soft-copper tie-wires. For curves, a construction similar to that shown in Fig. 51 is used. The trolley wire is held directly under the messenger cable, and wooden strain insulators *a* insulate the messenger cable and trolley wire from the poles.

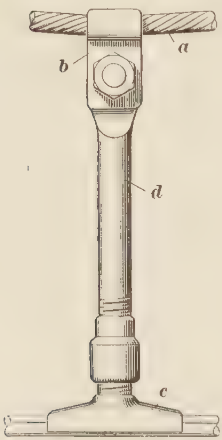


FIG. 53

93. A side-bracket construction is shown in Fig. 52, where *a* is the bracket arm made of **T** iron; *b*, the insulator; *c*, the messenger cable; *d*, the trolley wire; and *e*, the hangers connecting the messenger wire and the trolley.

The messenger wire sags between the supporting poles, but the trolley wire maintains almost the same height above the track throughout its length. The trolley wire is supported

about 17 inches below the messenger cable, at the poles, and the distance between the messenger cable and the trolley wire gradually decreases toward the center of the span

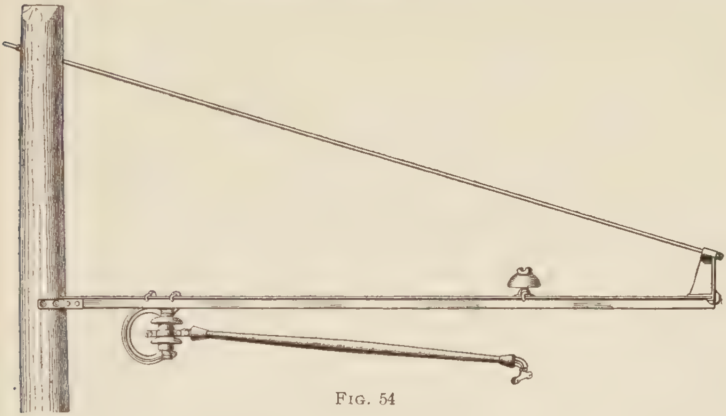


Fig. 54

between the poles. The type of hangers used for this construction is shown in Fig. 53. The messenger wire *a* is encircled by a clamp *b*. A clamp *c* holds the top of the grooved trolley wire, leaving the bottom of the wire unobstructed for the passage of the trolley shoe. A length of pipe *d* joins the clamps *a* and *c*. This pipe varies in length, according to the position of the hanger.

94. On curves of large radius, and at intervals of about 440 feet on a straight track, a supplemental rod made of hardwood is attached to the bracket. One end of the rod is attached to the bracket arm, and the outer end of the rod terminates in a clamp, which is secured to the

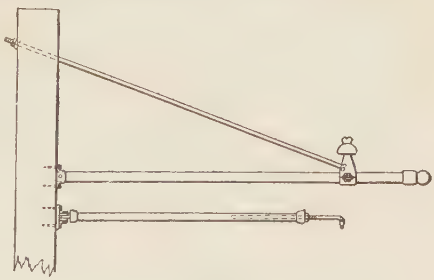


Fig. 55

trolley wire. This serves to keep the catenary structure in an upright position. A bracket thus equipped is called a **steady-strain bracket,** and is shown in Fig. 54. Another, but

somewhat similar; construction for the same purpose is shown in Fig. 55. A portion of a line equipped with the type of bracket shown in Fig. 54 may be seen in Fig. 56.

FIG. 56

95. When an ordinary trolley wheel is to be employed as a current-collecting device, the trolley wire is placed over the center of the track. When a sliding contact shoe is to be used, however, the wire is placed alternately $8\frac{1}{2}$ inches to

the right and the left of the center line of the track, so as to distribute the wear on the shoe.

96. The section insulators, pull-off hangers, etc. are somewhat similar to those used in the ordinary low-tension system, with the exceptions that the insulation provided is much better and that both the messenger cable and the

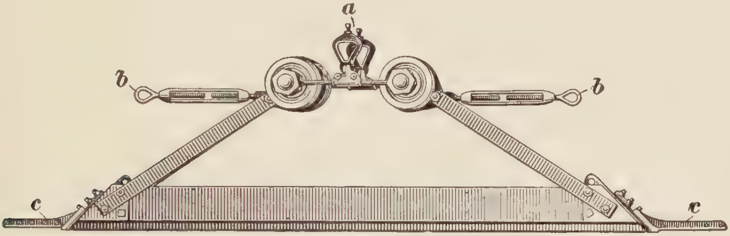


FIG. 57

trolley wire are mechanically connected to the devices, as shown in Fig. 57, which represents a section insulator. Clamps *a* are mounted on the **T**-iron support; the messenger cables are connected to *b*, and the trolley wires to *c*.

DOUBLE CATENARY

97. For heavy traffic roads having two or more tracks, a more substantial construction has been developed. Steel bridges spanning the tracks support a **double-catenary line construction.** In Fig. 58, *a*, *a*, are two messenger cables, from which the trolley wire *b* is suspended by triangular supports. This method of suspension results in a very rigid line construction. At intervals, anchor bridges are provided to bear the stresses of the line wires. Massive insulators mounted on the tops of the bridges insulate the catenary construction from the bridge structure. The double-catenary construction may also be supported on bracket arms projecting from poles at one side of the track, as shown in Fig. 59.

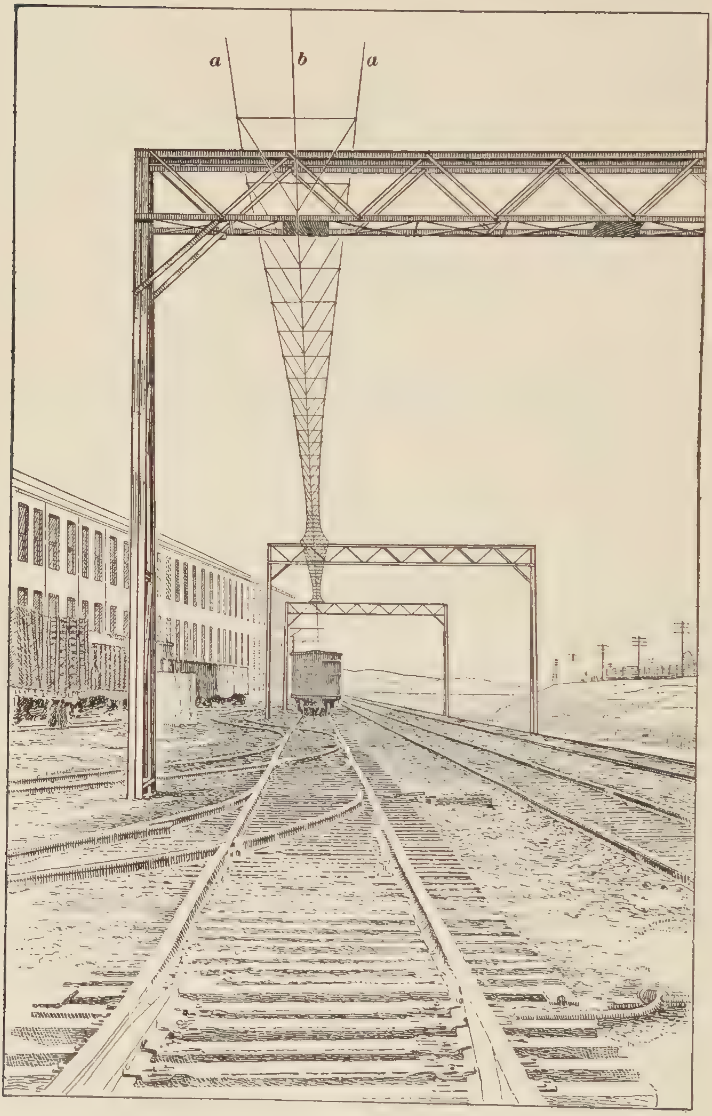


Fig. 58

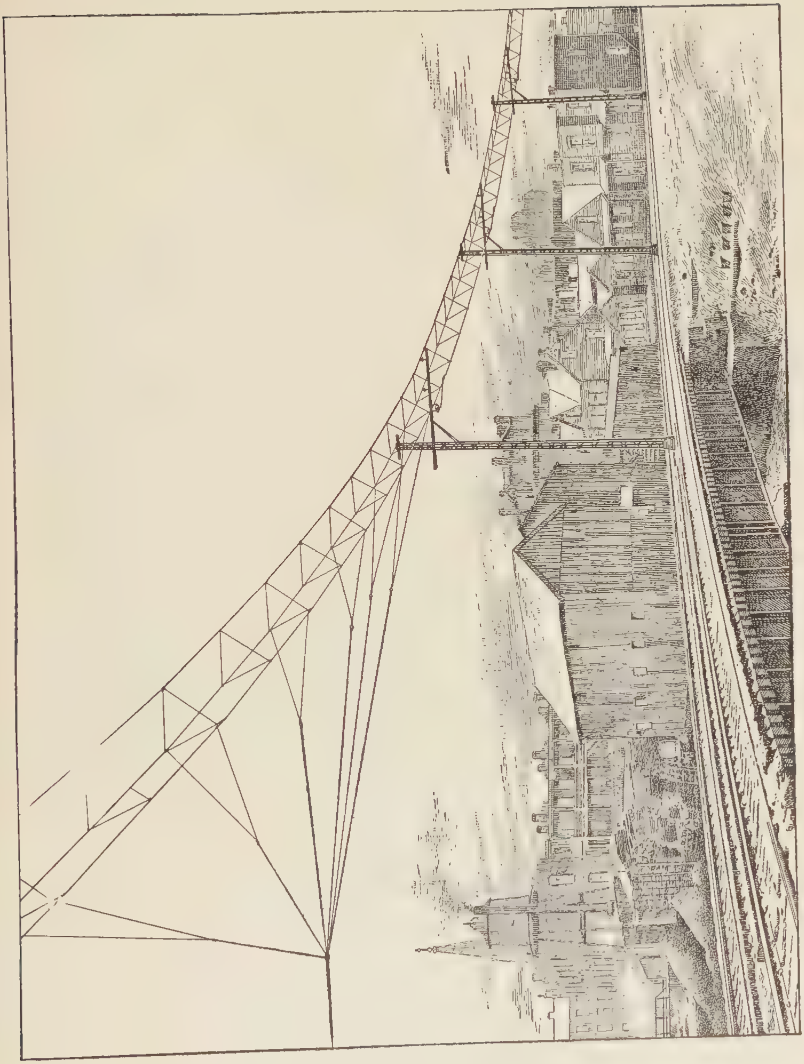


Fig. 59

SUBSTATIONS

98. Where a complete single-phase railway system is to be installed, single-phase generators are often used at the power station, although two- or three-phase generators may be employed. In Fig. 60 is shown the exterior, and in

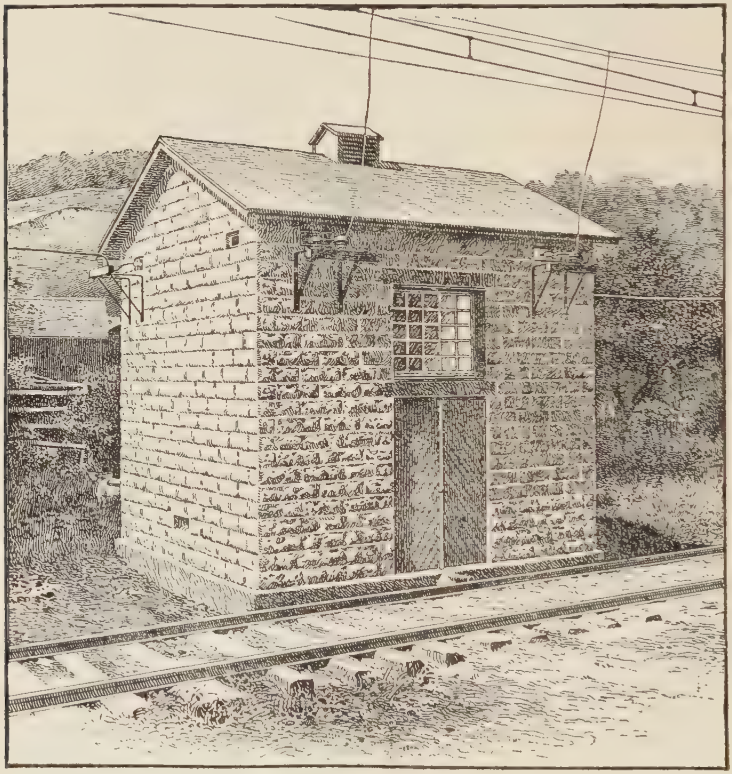


Fig. 60

Fig. 61 the interior, of a substation for a single-phase system. The current from the single-phase generator at the generating station is stepped up to a pressure of 22,000 volts, or perhaps higher, for the transmission lines. In the substations, step-down transformers *a*, *a*, Fig. 61, are installed. The low-tension sides of these transformers are connected between

the trolley wire and the ground. The trolley pressure varies in different installations, but is often 3,300 volts or higher.

The high-tension wires are provided with high-potential, fused circuit-breakers *b*, from which wires are connected to the primary coils of the transformers. One end of each of the secondary coils is grounded. The other ends of the sec-

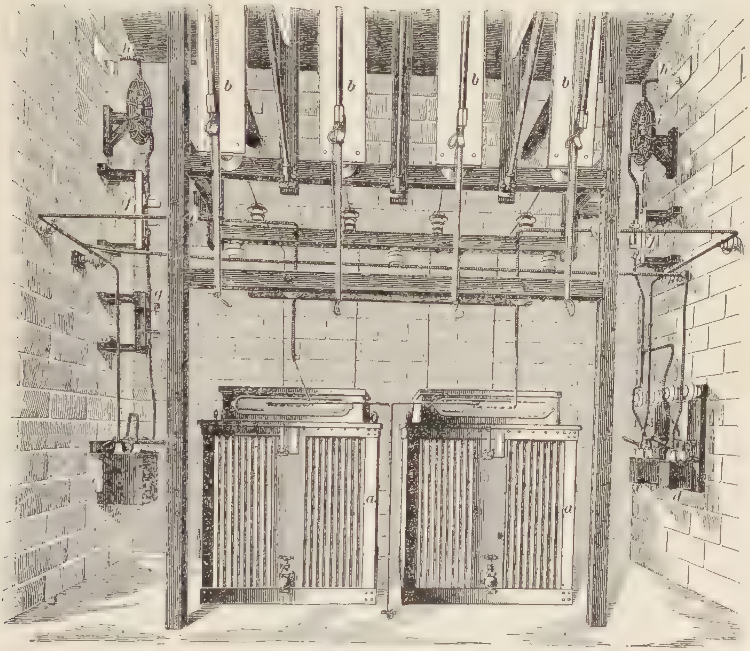


Fig. 61

ondary coils may be connected to either one or both of the outgoing trolley sections. Oil switches *c*, *d*, *e*, disconnecting switches *f*, and fuse block *g* assist in making connections between the secondary coils and the two trolley sections *h*, *h*. Coils *i* are choke coils for the lightning-arrester equipment.

99. A type of high-potential, fused circuit-breaker made by the Westinghouse Company is shown in Fig. 62. The wooden pole *a* has clips mounted on it, so that the pole may be easily connected to the high-tension terminals *b*, *c*. The

wooden pole *d* is hinged to *a* at *e*. A flexible wire is run from the lower clip on *a*, through *d*, to a clip on the top of *d*.

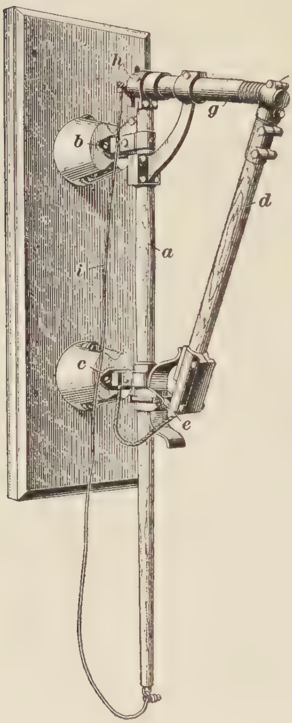


Fig. 62

A fuse wire is connected to *f*, passes through an expulsion tube *g*, and is fastened to a clamp *h* that is connected to the upper clip on *a*. The fuse forms part of the circuit between the terminals *b* and *c*. When the fuse blows, the arm *d* swings downwards; the arc is partly drawn out by this action and partly blown out by the confined gases in *g*. By pulling on string *i*, the clamp *h* is opened, the fuse wire released, and the switch opened. When renewing a fuse, the whole device is taken down by disconnecting the pole *a* from the terminals *b*, *c*.

100. In Fig. 63 is shown one method of connecting up the apparatus in a substation. The detailed arrangements vary in different stations. With the arrangement shown, either one or both of the transformers may be connected to either one or both of the trolley sections.

101. In Fig. 64 is shown another wiring diagram for a substation. Automatic safety devices are provided to open the circuit in case of a serious short circuit, or in case the trolley line, due to some disorder causes the secondary coil to act as a primary.

The *time-limit relay* consists of a device—usually containing a magnet and clockwork—that starts to operate in case of excessive current, but does not close the circuit through the tripping coil of the oil switch, and thus open it, until a short

interval of time elapses. If the short circuit persists, the oil switch is opened; but if it is of very short duration, the tripping coil is not energized and the oil switch remains closed.

The *differential relay* is so arranged that, under normal conditions, the currents set up in the secondary coils of the two series transformers, shown just above and below the

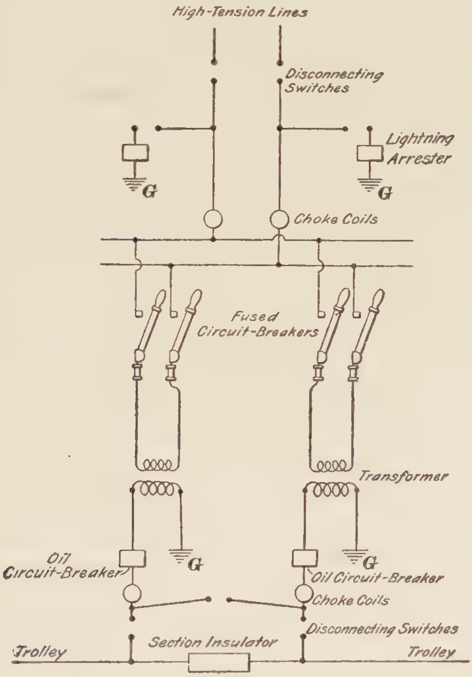


FIG. 63

main transformers, flow through each other and the **V**-shaped switch. In case of disorder in the power transformers, the current in one series transformer will oppose the current in the other series transformer. Current will flow through the operating coil of the **V**-shaped switch, opening it, and thus allowing the current to flow through the tripping coils and to open the oil switches.

On long roads built for heavy service, substations are installed at quite frequent intervals, in order to reduce the

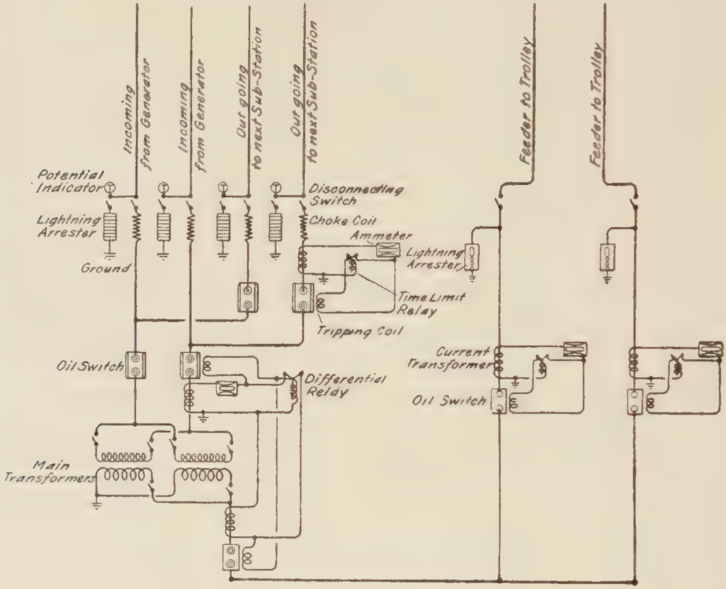


FIG. 64

current flowing through the rails and thus prevent a large drop in the voltage.

A SERIES

OF

QUESTIONS AND EXAMPLES

RELATING TO THE SUBJECTS
TREATED OF IN THIS VOLUME.

It will be noticed that the Examination Questions that follow have been divided into sections, which have been given the same numbers as the Instruction Papers to which they refer. No attempt should be made to answer any of the questions or to solve any of the examples until that portion of the text having the same section number as the section in which the questions or examples occur has been carefully studied.

ELECTRIC-RAILWAY SYSTEMS

EXAMINATION QUESTIONS

(1) Name four methods that may be used for supplying current to street-car motors.

(2) What limits the voltage for railway purposes from 500 to 650 volts?

(3) Make a sketch showing the relation of a series booster to the other part of a direct-current railway system?

(4) What things, besides the load center, must be considered in most economically locating a power house?

(5) Why are single-phase alternating-current motors better than polyphase induction motors for railway operation?

(6) About what is the limiting distance from the power house to which it is profitable to run cars with the 500-volt direct-current system without the use of boosters?

(7) With respect to a street-car system, where should the power house be located, provided that the land be obtained and other conditions do not interfere?

(8) Suppose that in Fig. 21, W represents the center of a load of 200 kilowatts, W'' 100 kilowatts, and W' 300 kilowatts. Considering only the load, where should the power house for supplying the same be located, assuming the distances to be the same as given in Fig. 21? Illustrate your solution by means of a sketch.

(9) If a car with passengers weighs 12 tons and it is desired to propel it up a 5-per-cent. grade at a speed of 8 miles per hour, how many horsepower must be expended

if the force required to propel the car on a level track is 20 pounds per ton? Ans. 30.7 H. P.

(10) Explain the method of supplying certain feeders with higher voltage than that of the regular station bus-bars by using a high-voltage bus. Illustrate by means of a sketch.

(11) What effort, in addition to that required to overcome train resistance, must be applied to give an acceleration of .9 mile per hour per second to a car weighing 25 tons? Ans. 2,052 lb.

(12) If it requires an effort of 90 pounds per ton to start a car on the level, what is the steepest grade on which the car can be started without wheel slippage, if 70 per cent. of the weight of the car rests on the drivers and the adhesion is 14 per cent. of the weight on drivers? Ans. 5.3 per cent.

(13) If it requires a force of 25 pounds per ton to move a car at a uniform rate on a level track, how many pounds per ton will be required to move it up a $3\frac{1}{2}$-per-cent. grade? Ans. 95 lb. per ton

(14) About how many watt-hours per ton-mile are required for the operations of interurban cars: (*a*) in limited service? (*b*) in local service?

(15) On a certain interurban road, similar to that described in Art. **53**, six cars are to be operated on limited service at an average speed of 32 miles per hour and eight cars on local service at an average speed of 23 miles per hour. The cars weigh 32 tons each and the total loss between power station and the cars amounts to 20 per cent. of the power required for the cars. (*a*) How much power will be required at the cars? (*b*) How much power must be supplied at the station? (*c*) What size of generating units and number of units would you consider suitable for the station?

Ans. $\begin{cases} (a) \ 960.64 \text{ K. W.} \\ (b) \ 1{,}152.77 \text{ K. W.} \end{cases}$

(16) Does the resistance offered by air increase with the speed of a car or train, and if so in about what proportion?

(17) If a car increases its speed from 5 miles per hour to 25 miles per hour in 15 seconds what is the acceleration in miles per hour per second? Ans. 1.33 mi. per hr. per sec.

(18) Make sketches of and explain two methods of operating cars by single-phase current: (*a*) when supplied from a single-phase transmission line; (*b*) when supplied from a three-phase transmission line.

(19) If a series booster is to carry current for feeders requiring, on the average, 500 amperes, and if the pressure is to be increased 200 volts, what should be the output of the booster, in kilowatts? Ans. 100 K. W.

LINE AND TRACK

(PART 1)

EXAMINATION QUESTIONS

(1) (*a*) Why is it necessary to offset the trolley wire from the center of the track on curves? (*b*) How many inches should the wire be offset on an 80-foot curve?

(2) Why is it desirable, in arranging the feeders for a railway system, to have the road divided into a number of sections each supplied by a separate feeder?

(3) If a copper railway feeder must have a cross-section of 650,000 circular mils for a given service, what should the cross-section be if aluminum were used instead?

Ans. 1,083,333 cir. mils

(4) (*a*) What three types of construction are generally used for the suspension of trolley wire? (*b*) State the locations to which each is best adapted.

(5) Calculate the resistance of 22 miles of double track composed of 90-pound rail, thoroughly bonded so that the conductivity of the joints is equal to that of an equivalent length of solid rail. Ans. .273 ohm

(6) What type of rail is well adapted for paved streets where the wagon traffic is very heavy?

(7) What features of the **T** rail make it a desirable type to use wherever possible?

(8) What is the cross-section, in square inches, of: (*a*) an 80-pound rail? (*b*) a 70-pound rail?

(9) If a 15-mile single-track road is to be laid with 80-pound rails, how many tons of rails will be required?

Ans. 2,112 tons

(10) (*a*) What substance in steel rails has the greatest influence on the resistance? (*b*) Give the composition of a mild steel suitable for conductor rails.

(11) If a conductor rail has an equivalent resistance of 8 times that of copper, what would be the resistance of 6,000 feet of 60-pound rail? Ans. .0679 ohm

(12) (*a*) What is the minimum number of line lightning arresters that should be provided per mile of line on street-railway systems? (*b*) How should the ground connection for these arresters be made?

(13) Of what material are span wires usually made?

(14) Describe one method of making a connection from the feeder to the trolley wire.

(15) Calculate the resistance of 8 miles of single-track road laid with 70-pound rails; neglect resistance of joints.

Ans. .256 ohm

LINE AND TRACK

(PART 2)

EXAMINATION QUESTIONS

(1) Describe the drop-of-potential method of testing for defective rail bonds and illustrate by means of a sketch.

(2) If a track cools from 100° to 60° F., what will be the resulting stress in the rails, assuming that they are firmly fastened and that electrically welded joints are used?

Ans. 8,667 lb.

(3) How does the conductivity of an electrically welded joint compare, approximately, with that of an equal length of solid rail?

(4) An 80-pound rail is bonded with two No. 0000 bonds, each 18 inches long. To how many feet of solid rail are the bonds equivalent in resistance, neglecting the resistance of the bond contacts? Ans. 3.62 ft.

(5) (*a*) Why is it necessary to cross-bond the rails of an electric-railway track? (*b*) At what intervals should the rails be cross-bonded?

(6) Explain, briefly, the principle of operation of the Conant bond tester, and illustrate by means of a sketch.

(7) Explain one method by which the resistance of the track-return circuit, taken as a whole, can be measured.

(8) (*a*) What kinds of wood are most commonly used for ties? (*b*) What are the usual dimensions for ties on tracks of standard gauge?

(9) In the Lorain surface-contact system, how is the surface-contact plate brought into electrical connection with the feeder when the car is over the plate?

(10) Make a sketch showing a suitable location of conductor rail with reference to the track on third-rail roads.

(11) What kinds of insulator are commonly used for supporting the contact rail on third-rail roads?

(12) Give, approximately, the current leakage per mile from a well-insulated third rail.

LINE CALCULATIONS

EXAMINATION QUESTIONS

(1) Suppose that a single-track trolley road 3 miles long fed from a power station at one end, as shown in Fig. I, has ten cars, requiring on an average 24 amperes per car. If the trolley wire is No. 00 and the track resistance, including bonds, is .006 ohm per 1,000 feet of single track (two lines of rails), what must be the size of the feeder in order that the drop shall not exceed 110 volts, even if the total load is

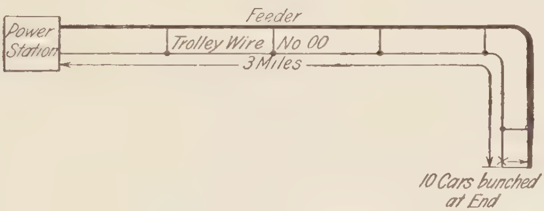


FIG. I

concentrated at the end of the road most distant from the power house? Assume the trolley wire to have the same conductivity as the soft-copper feeder.

Ans. 337,840 cir. mils

(2) What is the relation between the drop on a given line for the same total number of amperes with the load evenly distributed and with it all concentrated at the distant end of the line?

(3) After having properly calculated the size of feeder required to carry a given current with a given drop, what other property of the wire is it necessary to bear in mind?

(4) A trolley road fed from a power station located at the middle, as shown in Fig. II, has a double track 4 miles long and twelve cars, requiring on an average a current of 25 amperes per car. The trolley wire is No. 00, and has the same conductivity as the soft-copper feeder, and the track resistance, including bonds, is .0035 ohm per 1,000 feet of double track. What must be the size of the feeder in order that the drop shall not exceed 100 volts even if all the cars are concentrated at one end of the road?

Ans. 118,864 cir. mils, approx.

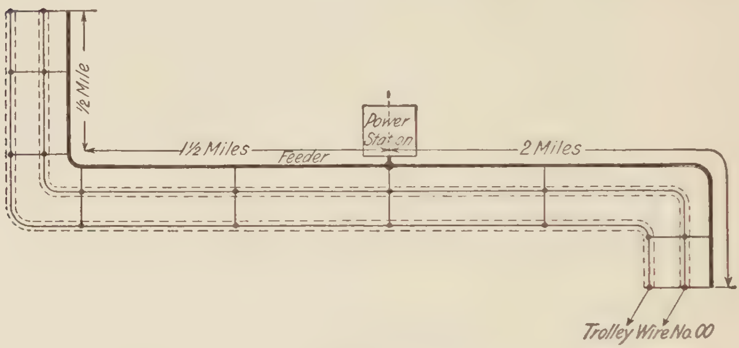


Fig. II

(5) What are some of the results of operating street cars on too low a voltage?

(6) What is meant by electrolysis in electric-railway work?

(7) What points on underground-cable sheaths, water pipes, etc. are liable to injury by electrolysis?

(8) Fig. III shows the layout of a single-track road operating twelve cars, each car requiring an average current of 25 amperes. The road is divided into three sections by means of line breakers, each section being provided with a No. 00 main having a cross-section of approximately 133,000 circular mils. The mains are fed by the feeders *1*, *2*, and *3*. Feeders running parallel to those for the overhead system and of the same size are to be used for

connecting the track circuit to the power station. The trolley wire is No. 00. Calculate the size of feeders required in order that the drop at any one of the cars, if they are all

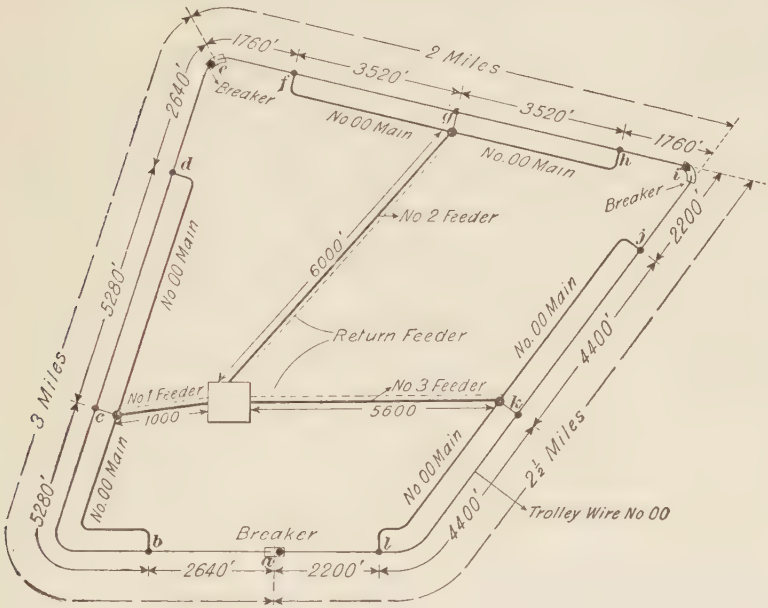


FIG. III

in the positions shown by the small round dots, shall not exceed 50 volts. Take the track resistance as .039 ohm per mile for two rails in parallel.

Ans. { Feeder *1*, No. 1 B. & S.
Feeder *2*, 350,000-cir.-mil cable
Feeder *3*, 350,000-cir.-mil cable

(9) State the main precautions that should be taken in order to prevent electrolytic action on underground pipes and conductors.

(10) (*a*) What is the difference between an ordinary double truck and a maximum-traction truck? (*b*) About what is the longest wheel base that can be used for single-truck cars in city traffic?

(11) Describe a method by which the current flowing in a pipe can be measured. Illustrate by means of a sketch.

(12) What is the usual method of suspending railway motors?

(13) Describe a method for measuring the E. M. F. between pipes and the adjacent earth. Illustrate by means of a sketch.

(14) What electric-railway systems are incapable of causing electrolysis in neighboring pipes or conductors?

MOTORS AND CONTROLLERS

EXAMINATION QUESTIONS

(1) Why are series-wound motors better suited to railway work than shunt-wound motors?

(2) The gear-ratio of the motors mounted on a car having 30-inch wheels is 5.07: how many revolutions per minute does the armature make when the car is running at a speed of 16 miles per hour? Ans. 908.5 rev. per min.

(3) In railway-motor operation is the average voltage applied to the motor the same as the line voltage and if not, why?

(4) (*a*) If the weight of a car is kept the same and the gear-ratio increased, what will be the effect on the current per motor and the speed of the car? (*b*) Will the speed of the car change in proportion to the change in gear-ratio and if not, why?

(5) If a car has a gear-ratio of 4.33 and is mounted on 30-inch wheels, what will be the tractive effort per motor when the current is such that the motor torque is 400 pound-feet? Ans. 1,385.6 lb.

(6) Of what materials are the field frame and pole pieces of modern direct-current railway motors usually made?

(7) Why are two-circuit or series windings used for the armatures of railway motors?

(8) Why is it necessary to use a dummy, or dead, coil in the Westinghouse 12A armature?

(9) What is the difference between the rheostatic and series-parallel methods of speed control for electric cars, and why is the latter method almost universally used in preference to the former?

(10) In Fig. 31, trace out the path of the current starting from controller trolley post T, when the controller is placed on the seventh notch.

(11) What is the difference between type K and type L controllers as regards the manner of changing from series to parallel?

(12) In Fig. 38, trace out the path of the current on the sixth notch, starting from T on the right-hand controller.

(13) What two methods may be used for controlling the speed of cars equipped with alternating-current series motors?

(14) Why is it desirable, in controllers for use on metallic-return systems, to have the main cylinder open on both sides of the circuit when thrown to the off-position?

ELECTRIC-CAR EQUIPMENT

EXAMINATION QUESTIONS

(1) Determine the size, according to the Underwriters' requirements, for the trunk wire of a car equipped with four 35-horsepower motors.

(2) What makeshift is sometimes used instead of a sleet wheel?

(3) What is the advantage of using both fuses and circuit-breakers to protect car-motor circuits?

(4) How may the size of copper wire to be used as a fuse for an equipment of given horsepower be determined?

(5) Describe one method of insulating the wires for heavy cars, such as are used on elevated roads.

(6) (*a*) On what principle are all electric heaters made? (*b*) What other heating systems are used with electric cars?

(7) What advantage has a headlight provided with both an arc and incandescent lamp?

(8) What are the main objections to existing single-truck brake riggings?

(9) (*a*) What is meant by a straight air brake? (*b*) Name the principal parts of a straight air-brake equipment.

(10) What is the object of the insulation hose or insulating joint used on independent-motor-driven compressor equipments?

(11) Why are engineer's valve handles made so as to be removable only on lap position?

(12) What is meant by: (*a*) standing travel? (*b*) running travel? (*c*) What kind of travel does an automatic slack adjuster regulate?

(13) Define train-line reduction, and state the object of a service reduction.

(14) What is meant by: (*a*) recharging the train line? (*b*) excess pressure?

MULTIPLE-UNIT SYSTEMS

(PART 1)

EXAMINATION QUESTIONS

(1) Name several advantages of installing motors on each of the cars composing a train.

(2) What is the object of the cut-out switch on type M cars?

(3) What means are taken to secure the safe maximum rate of acceleration with the C18 master controller?

(4) Why is it essential that the main controllers on all cars of a train act simultaneously?

(5) What is the purpose of the safety switch in the C6 master controller?

(6) What, in general, is the object of the interlock switches on the type M contactors?

(7) What is the purpose of the bus-line?

(8) What is the object of the circuit-breaker setting switch shown in Fig. 20?

(9) What advantages has the use of connection boxes in the type M control?

(10) Name the four forward positions of the C35 controller.

(11) Explain the action of the current-limit relay used in the automatic relay control.

(12) Name the purpose of each of the seven wires of the train cable in the automatic relay control.

(13) What is the object of the potential relay in the automatic relay control?

(14) In case maximum speed is desired, how should the controller handle in the automatic relay control be operated?

(15) What contactors are closed in the switching position of the master controller shown in Fig. 27?

MULTIPLE-UNIT SYSTEMS

(PART 2)

EXAMINATION QUESTIONS

(1) How is sticking of the unit-switch contacts prevented?

(2) How are the circuit-making and circuit-breaking devices on the Westinghouse unit-switch system of control operated?

(3) What is the object of the motor-control cut-out switch shown in Fig. 21?

(4) When the line switch and line relay as shown in Fig. 23 are open, what completes the control circuit so that the switch group may be tested?

(5) For what purpose is the reverser interlock on a unit-switch equipment used?

(6) Why are two sets of storage batteries used in the unit-switch control?

(7) What is the advantage of the rectangular switch group over the turret switch group?

(8) Describe briefly the action of the unit switch shown in Fig. 20.

(9) What unit switches are closed on the series-running position of the master controller shown in Fig. 23?

(10) When is the right-hand limit switch, Fig. 23, active in interrupting the control circuit?

(11) How is the master-controller handle shown in Fig. 5 moved: (*a*) for forward motion of the car? (*b*) for backward motion of the car?

(12) For what purpose is the Westinghouse limit switch used?

(13) What action occurs when the plug is inserted in the cut-out switch *L.-S.*, Fig. 23, and the controller turned so as to energize finger *5 A*?

(14) What is the object of the limit-switch cut-out in Fig. 23?

(15) In Fig. 24, what unit switches are closed on the switching position?

SINGLE-PHASE RAILWAY SYSTEM

EXAMINATION QUESTIONS

(1) How is the compensating field winding placed in the motor shown in Fig. 8?

(2) How is the electromotive force of self-induction kept at a low value in the main field coils of a single-phase, alternating-current motor?

(3) In connection with Fig. 35, state which unit switches are closed on the first notch in alternating-current operation.

(4) Why is the contact shoe on the pantagraph trolley made broad and long?

(5) When an alternating current flows through a series-wound motor, how is it that the rotation remains in one direction?

(6) Describe briefly the single-catenary line construction.

(7) What is the object of the compensating field winding on the field frame of a series alternating-current motor?

(8) In a type of autotransformer similar to that shown in Fig. 18, the primary current is 20 amperes and the current in the external secondary circuit is 220 amperes. What is the current in the secondary coil? Ans. 200 amperes

(9) What is the purpose of the resistance leads between the armature coils and the commutator on some types of alternating-current motors?

(10) In connection with Fig. 33, explain the method of raising the pantagraph trolley.

(11) When a contact-shoe trolley is used, what is the object of placing the trolley wire alternately to the right and the left of the center line of the track?

(12) What is the purpose of the resistance section SB, Fig. 37?

(13) What is the purpose of a steady-strain bracket?

(14) In connection with Fig. 39, state which contactors are closed on the first point of the master controller.

(15) Is the running voltage or the starting voltage (impressed on the terminals of an alternating-current motor) more nearly in phase with the current?

(16) In connection with Fig. 42, state which contactors are closed on the fifth point of the master controller in alternating-current operation.

(17) State two reasons for using preventive-reactance coils.

(18) How is the change-over switch, Fig. 35, operated for direct current?

(19) In connection with Fig. 26, explain briefly the method used to raise the electromotive force impressed on the motor terminals as the controller drum is advanced.

(20) (*a*) With the controller and autotransformer shown in Fig. 26, which taps are active on the third notch? (*b*) What electromotive force is impressed on the motor terminals on the third notch?

A KEY

TO ALL THE

QUESTIONS AND EXAMPLES

CONTAINED IN THE

EXAMINATION QUESTIONS

INCLUDED IN THIS VOLUME.

The Keys that follow have been divided into sections corresponding to the Examination Questions to which they refer, and have been given corresponding section numbers. The answers and solutions have been numbered to correspond with the questions. When the answer to a question involves a repetition of statements given in the Instruction Paper, the reader has been referred to a numbered article, the reading of which will enable him to answer the question himself.

To be of the greatest benefit, the Keys should be used sparingly. They should be used much in the same manner as a pupil would go to a teacher for instruction with regard to answering some example he was unable to solve. If used in this manner, the Keys will be of great help and assistance to the student, and will be a source of encouragement to him in studying the various papers composing the Course.

ELECTRIC-RAILWAY SYSTEMS

(1) The overhead-trolley, third-rail, open-conduit or slot, and electromagnetic or surface-contact methods. See Art. **4.**

(2) Considerations of safety; also, because it is difficult to build direct-current railway motors that will run without sparking or flashing on pressures above 650 volts. See Art. **3.**

(3) See Art. **19.** A sketch similar to Fig. 8, with explanation, is required.

(4) See Art. **34.**

(5) See Art. **2.**

(6) See Art. **16.**

(7) See Art. **32.**

(8) The center of gravity between W and W'' will be at a distance l from W such that $l \times W = (L - l)\ W''$. Substituting the proper values for W, L, and W'' in this equation gives $l \times 200 = (7 - l)\ 100$; simplifying, we get $200 \times l = 700 - 100 \times l$, which gives $l = \frac{700}{300} \doteq 2\frac{1}{3}$ mi. Hence, a load of 300 K. W., which we will call W''', $2\frac{1}{3}$ mi. from W may be represented as equivalent to both W and W''. Since W' is also 300 K. W., the center of gravity of W' and W''' will be half way between them. Hence, the best position for the power house, for the three loads, is at this center point, which is half way between W' and a point on the line joining W and W'', $2\frac{1}{3}$ mi. from W. See Art. **37.**

(9) If the force required on the level is 20 lb. per ton, the force on a 5-per-cent. grade will, according to formula **2,** be $20 + 20 \times 5 = 120$ lb. per ton. In formula **3,** $F = 120 \times 12 = 1{,}440$ lb. and $S = 8$ mi. per hr.; hence, H. P. $= \frac{8 \times 1{,}440}{375} = 30.7$. Ans.

(10) A sketch similar to Fig. 7, with explanation, is required. See Arts. **17** and **18.**

(11) Use formula **4**; $W_t = 25$, $A = .9$; hence, $F_a = 91.2 \times 25 \times .9 = 2{,}052$ lb. Ans.

(12) Use formula **5**; $a = .7$, $b = .14$, $f' = 90$; hence,

$$G = \frac{2{,}000 \times .7 \times .14 - 90}{20} = 5.3 \text{ per cent.} \quad \text{Ans.}$$

(13) Use formula **2**; $f = 25$, $G = 3\frac{1}{2}$, $f_g = 25 + 20 \times 3\frac{1}{2} = 95$ lb. per ton. Ans.

(14) (*a*) and (*b*) See Art. **53**.

(15) (*a*) The local cars run $23 \times 8 = 184$ car mi. per hr.; the limited cars run $32 \times 6 = 192$ car mi. per hr. Taking each ton-mile of local service as equivalent to 87.5 watt-hours, the total watt-hours expended per hour on the local cars will be $87.5 \times 184 \times 32 = 515{,}200$. The work done per hour on the limited cars will be, taking each ton-mile equivalent to 72.5 watt-hours, $72.5 \times 192 \times 32 = 445{,}440$ watt-hours. The total work done per hour is, therefore, 960,640 watt-hours, and in order to do this amount of work per hour, the average power or rate at which work is done must be 960,640 watts, or 960.64 K. W. Ans.

(*b*) If 20 per cent. of the power supplied is allowed for loss in the transmission, the amount lost will be $960.64 \times .2 = 192.13$ K. W. and the average power supplied from the station will be 1,152.77 K. W. Ans.

(*c*) To supply an average load of 1,152.77 K. W., it would probably be necessary to operate about 1,500 K. W. of generators in order to allow for load fluctuations and also supply the considerable current required for heating and lighting. The station could therefore be equipped with, say, three 800 K. W. machines, two of which, operated in parallel, would handle the load, the third being kept as a reserve. See Art **57**.

(16) See Art. **50**.

(17) The increase of speed during 15 sec. is 20 mi. per hr.; hence, the acceleration is $\frac{20}{15} = 1.33$ mi. per hr. per sec. See Art. **47**.

(18) (*a*) and (*b*) Sketches similar to Figs. 14 and 15, with accompanying explanation, are required.

(19) See Art. **21**.

LINE AND TRACK

(PART 1)

(1) (*a*) and (*b*) See Art. **23.**

(2) See Art. **7.**

(3) The cross-section of the aluminum cable will be $1\frac{2}{3}$ times that of the copper cable. Hence, the cross-section will be $650{,}000 \times 1\frac{2}{3} = 1{,}083{,}333$ cir. mils. Ans. See Art. **9.**

(4) (*a*) and (*b*) See Arts. **12, 13, 14, 15,** and **16.**

(5) Using formula **5,** the resistance per mile of single rail will be, since $W_y = 90$ lb., $R_m = \frac{4.48}{W_y} = \frac{4.48}{90}$. Since the road is double track, the resistance per mile will be one-fourth this amount, or $\frac{1.12}{90}$, and the resistance of 22 mi. will be $\frac{1.12}{90} \times 22 = .273$ ohm. Ans.

(6) The groove rail. See Art. **50.**

(7) See Art. **47.**

(8) (*a*) and (*b*) See formula **1.**

(9) From formula **2,** the weight, in tons, per mile for a single track laid with 80-lb. rails is $W_t = 1.76 \times 80 = 140.8$ and for 15 mi. the weight would be $140.8 \times 15 = 2{,}112$ tons. Ans.

(10) (*a*) and (*b*) See Art. **43.**

(11) Formula **7** gives the resistance per thousand feet of 60-lb. rail, as $R' = \frac{.679}{60}$. For 6,000 ft. the resistance will be $\frac{.679}{60} \times 6 = .0679$ ohm. Ans.

(12) (*a*) and (*b*) See Art. **38.**

(13) See Art. **26.**

(14) See Art. **37.**

(15) From formula **5**, the resistance per mile for a single 70-lb. rail is $R_m = \frac{4.48}{70}$, and for two rails in parallel $\frac{2.24}{70}$. The resistance of 8 mi. will therefore be $\frac{2.24}{70} \times 8 = .256$ ohm. Ans.

LINE AND TRACK

(PART 2)

(1) See Art. **27.** Illustrate by means of a sketch similar to Fig. 28.

(2) The decrease in temperature is 40° F. and from Art. **4** the rail will contract .0000065 of its length for each degree, making a total change of $.0000065 \times 40 = .00026$ of its length. A stress of 1,000 lb. per sq. in. will stretch steel .00003 of its length; hence, the stress in the case must be $\frac{.00026}{.00003} \times 1{,}000 = 8{,}667$ lb. Ans.

(3) Its conductivity varies from 125 to 166 per cent. of that of an equal length of solid rail. See Table I.

(4) From Table II, two No. 0000 bonds 1 ft. long are equivalent in resistance to 2.41 ft. of 80-lb. rail. Two bonds 18 in. in length will therefore be equivalent to $2.41 \times \frac{18}{12} = 3.62$ ft., approximately. Ans.

(5) (*a*) and (*b*). See Art. **24.**

(6) See Art. **28.** A brief explanation illustrated by a sketch similar to Fig. 30 is required.

(7) See Art. **31.** Illustrate your explanation by referring to a sketch similar to Fig. 31.

(8) (*a*) and (*b*). See Art. **33.**

(9) See Art. **56.**

(10) See Art. **46.**

(11) See Art. **50.**

(12) From .057 ampere per mile in wet weather to .023 ampere per mile in dry weather. This assumes that there are no leaky cables at highway crossings. See Art. **51.**

LINE CALCULATIONS

(1) The total resistance of the track circuit, see Fig. 1, is $.006 \times \frac{5,280}{1,000} \times 3 = .095$ ohm. The drop in the track circuit is $.095 \times 24 \times 10 = 22.8$ volts. This leaves $110 - 22.8 = 87.2$ volts for the drop e in the feeder and trolley wire. By substituting the proper quantities, $L = 5,280 \times 3 = 15,840$ ft. and $I = 24 \times 10 = 240$ amperes, in formula **1**, which is, cir. mils $= \frac{10.8\,L\,I}{e}$, the total number of circular mils required is obtained. Thus, cir. mils $= \frac{10.8 \times 15,840 \times 240}{87.2} = 470,840$. No. 00 trolley wire has a cross-section of approximately 133,000 cir. mils. The number

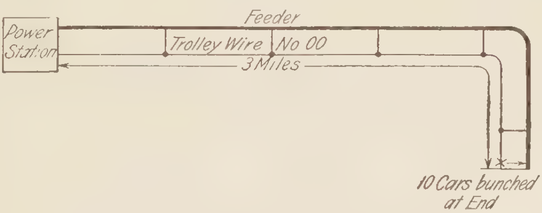


FIG. 1

of circular mils required in the feeder, since the trolley wire and feeder are in parallel, is $470,840 - 133,000 = 337,840$. A standard 300,000-cir.-mil cable would probably be used. See Arts. **5** and **6**.

(2) See Art. **9**.

(3) See Art. **15**.

(4) Since the power station, see Fig. 2, is at the middle of the road, the resistance of the track circuit from the power house to either end is $.0035 \times \frac{5,280}{1,000} \times 2 = .037$ ohm, nearly. The drop in the track circuit to one end is $.037 \times 25 \times 12 = 11.1$ volts. This leaves $100 - 11.1 = 88.9$ volts for the drop in the feeder and the two trolley wires. The distance is $5,280 \times 2 = 10,560$ ft., and by substituting in formula **1**, we have cir. mils $= \frac{10.8 \times 10,560 \times 300}{88.9} = 384,864$, approximately. The two

No. 00 trolley wires provide 2 × 133,000 = 266,000 cir. mils. Hence, the number of circular mils required in the feeder, since the trolley wire and feeder are in parallel, is 384,864 − 266,000 = 118,864. This is between a No. 0 and No. 00. It would be advisable to use the latter size.

(5) See Art. **16**.

(6) See Arts. **17** and **18**.

(7) Points where current flows from the pipe or cable into the ground. See Art. **18**.

(8) By examining the layout of the road, see Fig. 3, and noting the loads on the three sections, it is seen that the maximum drop on the section supplied by feeder No. *1* will be at end *e*; on the section supplied by feeder No. *2*, at end *i*; and on the remaining section, at end *a*.

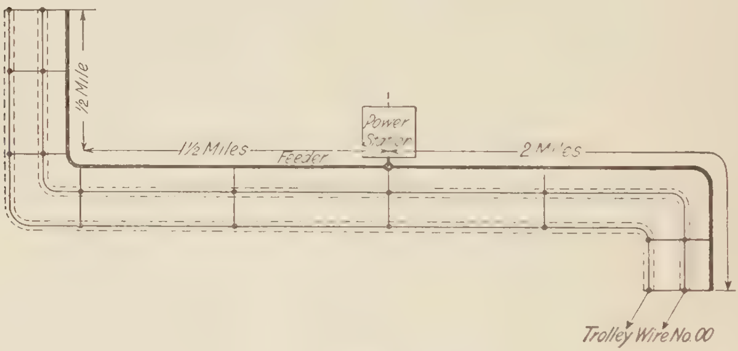


FIG. 2

Hence, the drop at these points only need be considered. The resistance of the track is .039 ohm per mile; hence, the following resistances will be used for calculating the drop in the track:

For a 1,760-ft. section, $\frac{1,760}{5,280} \times .039 = .013$ ohm

For a 3,520-ft. section, $\frac{3,520}{5,280} \times .039 = .026$ ohm

For a 2,640-ft. section, $\frac{2,640}{5,280} \times .039 = .0195$ ohm

For a 2,200-ft. section, $\frac{2,200}{5,280} \times .039 = .0163$ ohm

For a 4,400-ft. section, $\frac{4,400}{5,280} \times .039 = .0325$ ohm

Section No. 1.—The drop in the track from *d* to *e* is .0195 × 25 = .49 volt, approximately, and in the track section *c d*, .039 × 50 = 1.95 volts.

The total drop in the track between c and e is therefore $.49 + 1.95 = 2.44$ volts. The drop in the trolley wire from d to e is, since the current is 25 amperes and the cross-section of the trolley wire 133,000 cir. mils, $e = \frac{10.8 \times 2,640 \times 25}{133,000} = 5.36$ volts. From c to d the total cross-section is 266,000 cir. mils, and the current 50 amperes; hence, the drop between c and d in the overhead work is $e = \frac{10.8 \times 5,280 \times 50}{266,000} = 10.72$ volts. The total drop from c to e in track and overhead work

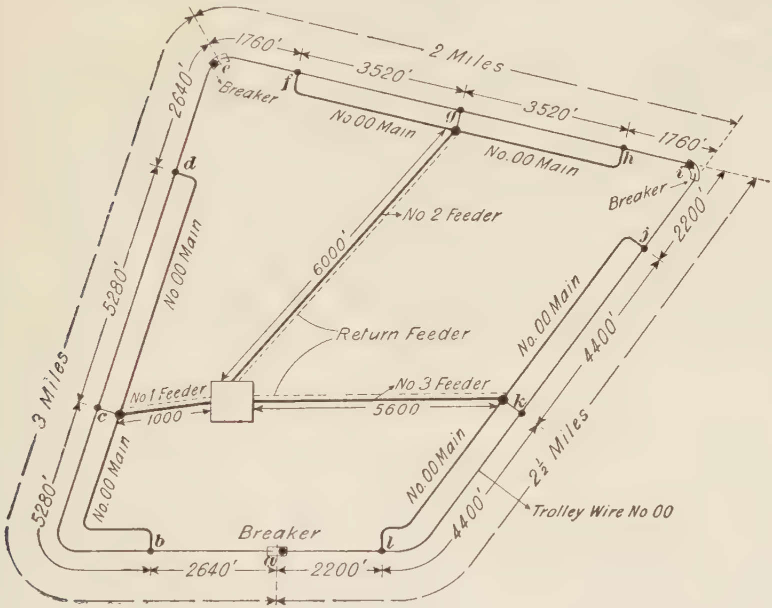


FIG. 3

is then $2.44 + 5.36 + 10.72 = 18.52$ volts. This leaves $50 - 18.52 = 31.48$ volts for the drop in outgoing and return feeders. The total length of these is 2,000 ft. and the current 100 amperes; hence, for the No. *1* feeders, both outgoing and return, cir. mils $= \frac{10.8 \times 2,000 \times 100}{31.48} = 68,615$. A No. 2 B. & S. wire will be nearly large enough, but it would be better to install a No. 1. The distance in this case is quite short, and a comparatively small feeder can carry the current with the allowable limit.

Section No. 2.—The drop in the section of track hi is $.013 \times 25 = .33$ volt, approximately; and in section gh $.026 \times 50 = 1.3$ volts;

hence, total drop in track from g to i is $.33 + 1.3 = 1.63$ volts. The drop in the trolley wire from h to i is, $e = \frac{10.8 \times 1,760 \times 25}{133,000} = 3.57$ volts; and in the overhead wires from g to h, $e = \frac{10.8 \times 3,520 \times 50}{266,000} = 7.14$ volts. The total drop from g to i in overhead line work and track is thus $1.63 + 3.57 + 7.14 = 12.34$ volts, leaving $50 - 12.34 = 37.66$ volts for the drop in outgoing and return feeders No. *2*. The length (both ways) of these feeders is 12,000 ft., and the current supplied 100 amperes; hence, cir. mils $= \frac{10.8 \times 12,000 \times 100}{37.66} = 344,132$. A 350,000-cir.-mil cable will therefore be suitable for this section.

Section No. 3.—Taking the car at a, the drop in the track from l to a is $.0163 \times 25 = .408$, approximately. The drop from k to l is $.0325 \times 50 = 1.63$ volts, approximately, and the total drop in the track $.408 + 1.63 = 2.038$, or say, 2.04 volts. The drop in the trolley wire from l to a is, $e = \frac{10.8 \times 2,200 \times 25}{133,000} = 4.46$ volts; and from k to l, $e = \frac{10.8 \times 4,400 \times 50}{266,000} = 8.93$ volts. Thus, the total drop from k to a is $2.04 + 4.46 + 8.93 = 15.43$ volts, leaving $50 - 15.43 = 34.57$ volts drop in outgoing and return feeders No. *3*. The total length in feeders No. *3* is 11,200 ft., and the current 100 amperes; hence, cir. mils $= \frac{10.8 \times 11,200 \times 100}{34.57} = 349,898$. A cable of 350,000-cir.-mils cross-section will therefore be suitable for this section also.

(9) See Art. **22**.

(10) (*a*) and (*b*) See Arts. **42** and **43**.

(11) Describe, briefly, the method given in Art. **23** and explain by referring to a sketch similar to Fig. 11.

(12) See Art. **47**.

(13) Describe the test given in Art. **21** and refer to a sketch similar to Fig. 10.

(14) See Art. **24**.

MOTORS AND CONTROLLERS

(1) See Art. **1.**

(2) For a speed of 16 mi. per hr., Table I, the revolutions per minute of the car axles mounted on 30-in. wheels will be 179.2. The speed of the motor armatures will therefore be $179.2 \times 5.07 = 908.5$ rev. per min. Ans. See Art. **2.**

(3) See Art. **7.**

(4) (*a*) and (*b*) See Art. **17.**

(5) From formula **1,** $F = \frac{24\,F'r}{d''} \times \frac{n'}{n}$. In this case, $F'r = 400$, $d'' = 30$, and $\frac{n'}{n} = 4.33$; hence, $F = \frac{24 \times 400}{30} \times 4.33 = 1{,}385.6$ lb. Ans.

(6) See Art. **20.**

(7) See Art. **34.**

(8) See Art. **33.**

(9) See Arts. **49** and **57.**

(10)
$$T\text{-}M\text{-}x\text{-}y\text{-}T\text{-}a\text{-}R_3\text{-}R_3\text{-}r_3\text{-}r_4\text{-}R_4\text{-}t\text{-}\left\{\begin{array}{l} 19\text{-}19\text{-}19\text{-}1\text{-}A_1\text{-}A_1\text{-}A_1\text{-}A\,A_1\text{-}A\,A_1\text{-}A\,A_1\text{-}2\text{-}F_1\text{-}F_1\text{-}F_1\text{-}E_1\text{-}E_1\text{-}E_1\text{-}E_1\text{-}d \\ 19\text{-}b\text{-}15\text{-}15\text{-}15\text{-}15\text{-}3\text{-}A_2\text{-}A_2\text{-}A_2\text{-}A\,A_2\text{-}A\,A_2\text{-}A\,A_2\text{-}4\text{-}F_2\text{-}F_2\text{-}F_2\text{-}F_2\text{-}E_2 \end{array}\right\}\text{-}G$$

(11) See Art. **58.**

(12)
$$T\text{-}1\text{-}R_2\text{-}R_2\text{-}R_2\text{-}R_5\text{-}R_5\text{-}\left\{\begin{array}{l} 19\left\{\begin{array}{l} 19\text{-}A_1\text{-}A_1\text{-}A_1\text{-}A\,A_1\text{-}A\,A_1\text{-}A\,A_1\text{-}F_1\text{-}F_1\text{-}F_1\text{-}E_1\text{-}E_1\text{-}E_1\text{-}4 \\ 19\text{-}19'\text{-}A_3\text{-}A_3\text{-}A\,A_3\text{-}A\,A_3\text{-}F_3\text{-}F_3\text{-}E_3\text{-}E_3\text{-}E_3\text{-}4 \end{array}\right\}\text{-}G \\ 19\text{-}2\text{-}15\text{-}15\left\{\begin{array}{l} 15\text{-}A_2\text{-}A_2\text{-}A_2\text{-}A\,A_2\text{-}A\,A_2\text{-}A\,A_2\text{-}F_2\text{-}F_2\text{-}F_2\text{-}E_2 \\ 15'\text{-}A_4\text{-}A_4\text{-}A\,A_4\text{-}A\,A_4\text{-}F_4\text{-}F_4\text{-}E_4 \end{array}\right\}\text{-}G \end{array}\right.$$

(13) See Arts. **76, 77,** and **78.**

(14) See Art. **69.**

ELECTRIC-CAR EQUIPMENT

(1) The total horsepower is $4 \times 35 = 140$, which is equivalent to $140 \times 746 = 104{,}440$ watts. If the voltage is 500, the current will be $104{,}440 \div 500 = 208.88$ amperes. From Table I, 40 per cent. of this full load current is to be taken; that is, $.40 \times 208.88 = 83.5$, or say, 84 amperes. From Table II, it is seen that No. 2 wire is the required size. Ans.

(2) See Art. **10.**

(3) See Art. **17.**

(4) See Art. **18.**

(5) See Art. **25.** A short description with reference to Fig. 27 is required.

(6) (*a*) See Art. **28.**
(*b*) See Art. **31.**

(7) See Art. **36.**

(8) See Art. **42.**

(9) (*a*) See Art. **46.**
(*b*) See Art. **47.**

(10) See Art. **65.**

(11) See Art. **53.**

(12) (*a*), (*b*), and (*c*) See Art. **70.**

(13) See Art. **80.**

(14) (*a*) See Art. **80.**
(*b*) See Art. **83.**

MULTIPLE-UNIT SYSTEMS
(PART 1)

(1) See Art. **2**.

(2) See Art. **19**.

(3) See Art. **29**.

(4) See Art. **6**.

(5) See Art. **9**.

(6) See Art. **14**.

(7) See Art. **30**.

(8) See Art. **31**.

(9) See Art. **7**.

(10) See Art. **33**.

(11) See Arts. **34** and **41**.

(12) See Art. **38**.

(13) See Art. **35**.

(14) See Art. **40**.

(15) See Art. **40** and Figs. 27 and 28.

MULTIPLE-UNIT SYSTEMS

(PART 2)

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(1) See Arts. **3** and **21.**

(2) See Art. **1.**

(3) See Art. **22.**

(4) See Art. **24.**

(5) See Art. **5.**

(6) See Art. **1.**

(7) See Art. **20.**

(8) See Art. **21.**

(9) See schematic diagram, Fig. 23, and Art. **26.**

(10) See Art. **28.**

(11) See Art. **4.**

(12) See Art. **8.**

(13) See Art. **24.**

(14) See Art. **24.**

(15) See schematic diagram, Fig. 24, and Art. **30.**

SINGLE-PHASE RAILWAY SYSTEM

(1) See Art. **17.**

(2) See Art. **4.**

(3) See Art. **62.**

(4) See Art. **87.**

(5) See Art. **3.**

(6) See Art. **91.**

(7) See Art. **5.**

(8) See Art. **24.** 220 − 20 = 200 amperes. Ans.

(9) See Art. **12.**

(10) See Art. **50.**

(11) See Arts. **87** and **95.**

(12) See Art. **69.**

(13) See Art. **94.**

(14) See Figs. 39 and 40, and Art. **74.**

(15) See Fig. 6 and Art. **15.**

(16) See Figs. 42 and 43, and Art. **84.**

(17) See Art. **28.**

(18) See Art. **59.**

(19) See Figs. 26 and 27, and Arts. **31** to **36,** inclusive.

(20) See Art. **34.**

INDEX

NOTE.—All items in this index refer first to the section (see the Preface) and then to the page of the section. Thus, "Automatic air brakes, §41, p68" means that automatic air brakes will be found on page 68 of section 41.

Y